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**The Application of Cogeneration Systems  
to the Cooling of Food and Buildings  
in East Timor**

**A thesis presented in partial fulfilment of the requirements for  
The Degree of Master of Technology at Massey University  
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## ABSTRACT

Cogeneration is generation of both heat and power simultaneously using a single primary energy input. Cogeneration recovers “waste heat” from a conventional power generation plant to produce useful energy, leading to the increased overall efficiency of fuel input. This also achieves cost savings, and reduces greenhouse gas emissions where fossil fuels are used.

The objectives of this study are to assess the technical and economic viability of a cogeneration system for the cooling of food and buildings in East Timor. The findings of this research provide a basis for recommending action and further research to East Timor’s decision-makers on energy issues. Technical assessments in this study focus on cooling, electricity demand, and fuel supply as the basis for choosing the type and size of a cogeneration system. The financial viability of the cogeneration system is assessed using net present value (NPV) and sensitivity analysis. The NPV of the cogeneration system is compared with the NPV of conventional energy supply for cooling and electricity.

There is low demand for cooling for comfort and food preservation in East Timor, due to low levels of industrial and commercial investment, and the vast majority of people still living in poverty. Although cooling demand is low overall, numerous government and commercial buildings have installed cooling systems. In this study, six buildings (2 office buildings, a bank, a hotel, a university and a mini-market) were selected based on their relatively high cooling demand and their geographic proximity to one another.

The cooling demand of these six buildings was modeled based on a room-by-room approach. The results showed that their overall hourly cooling demand averages 600 kilowatt-cooling, while peak load was 707 kilowatt-cooling. This cooling demand was primarily driven by ambient temperature, number of people present and lighting load.

Power demand in East Timor is low. The total operable power supply capacity for the entire country is 22 megawatts, of which more than half is located in Dili. Electricity demand is predominantly driven by residential consumption, rather than commercial and industrial consumption. Although there is low electricity demand, East

Timor faces an immediate electricity deficit of 24 megawatts, which is higher than the existing operable capacity. In the six selected buildings, the overall peak and average electricity loads were 489 kW and 422 kW respectively. This load was mainly driven by air conditioning, computers, and lighting applications during working hours.

Electricity generation relies on diesel, which is imported from Indonesia. Diesel will remain the main source to generate electricity due to a lack of feasible alternatives. East Timor is rich in natural gas both offshore and onshore. However, until now there has been no plan to provide natural gas distribution pipelines to East Timor.

Based on the cooling and electricity demand and fuel availability, diesel was chosen to drive the cogeneration systems. The size of the cogeneration system was selected so as to fulfill both the electricity demand in the six selected buildings and be able to export surplus to the local grid. There are two reasons for employing a larger engine capacity. Firstly, a small engine will not be able to generate sufficient heat to drive an absorption cooling system with a capacity of 600 kilowatt. Secondly, export electricity will increase revenues generated from the cogeneration plant.

Financially, the net present value (NPV) of both the cogeneration system and the conventional energy supply system were lower than zero, which means that neither system can be viable financially. The cogeneration system's NPV was lower than that for the conventional energy supply system, due to its higher capital and operating costs. High operating costs were due to fuel costs, with low revenues being due to heavy subsidies on electricity. If fuel and electricity subsidies were removed, a cogeneration system could become a more attractive option compared to a conventional system. However, removing the electricity subsidy would result in the large majority of people being unable to afford electricity.

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# CHAPTER 1

## INTRODUCTION

### 1.1. General Background

East Timor is located about 750 km north of Australia. It shares boundaries with Indonesia in the west, east and north, while in the south is the Timor Sea. The territory of East Timor consists of the half-part of Timor Island, including the offshore Islands of Atauro and Jaco, and an enclave, Oecusse, on the north coast of the Indonesian territory of West Timor. East Timor has an overall land area of approximately 14,609 square kilometres. The population in the territory is estimated to be around 800,000 people in 2001, who are mostly settled in the north coast.

East Timor is a former colony of Portugal. In 1976, Indonesia unilaterally annexed East Timor as its 27<sup>th</sup> province. However, the United Nations Organisation rejected this annexation and considered Portugal as the administrative authority of the territory. The UN demanded that Indonesia withdraw its troops from East Timor and let the East Timorese people exercise their own right to self-determination freely and without any interference, as stated in the Security Council and the General Assembly Resolution 389, 1976 and 31/53, Paragraph 5, 1976 respectively.

In April 1999, the Indonesian government under President Habibie offered two options to the East Timorese people, namely to vote to accept the proposal of special autonomous region under Indonesian rule; or to reject the proposal leading to independence. The vote was held on 30<sup>th</sup> August 1999, and the result showed that 78.5 percent of East Timorese people rejected the autonomy proposal offered by the Indonesian Government. Post-referendum, militias and Indonesian soldiers expressed their dissatisfaction by destroying a large part of the country, leaving the economic infrastructure of the territory severely damaged.

In October 1999, the Indonesian government ratified the results of the East Timorese vote and acknowledged the establishment of the United Nations Transitional Administration in East Timor (UNTAET), which is mandated by the United Nations Security Council to establish a democratic government in East

Timor. The first democratic election in the territory post-colonial occupation was held in August 2001 in order to elect members of the constituent assembly leading to the territory's fully independence in May 2002.

## **1.2. Economy**

The economy of East Timor relies primarily on the agricultural sector, which contributes almost 40 percent to the gross domestic product (GDP) and absorbs nearly 85 percent of its workforce. The main agricultural products are coffee, rice and maize. Coffee is the only export crop (Pedersen and Arneberg, 1999).

The violence of September 1999 severely damaged 50 percent of the economic infrastructure, such as commercial and government buildings and the power sector. Consequently, the GDP dropped from US\$375 million in the year 1998 to US\$228 million in the year 1999 (World Bank, 1999 and Valdivieso, 2000).

In the year 2000, the GDP of the country rose 15%, which was driven by construction, commerce, trade and basic services. This growth was largely contributed by the presence of United Nations (UN) staff and other expatriates, who have stimulated consumption and some private investment. However, these investments were predominantly short-term within the services sector (Valdivieso and Lopez-Mejia, 2001).

The future economy of East Timor will depend on a number of main sectors: agriculture, oil and gas, mining (i.e. marble and manganese), fisheries and tourism. The agricultural sector will provide large numbers of jobs, while coffee remains the main exporting commodity (Saldanha and Da Costa, 1998).

Oil and gas will contribute more than half of East Timor's income. In 2000, East Timor received the first royalty from oil and gas exploitation in the Timor Gap, of US\$3 million. This amount is predicted to increase more than ten times per annum by the year 2007, when the Bayu-Udan project operated by Phillips Petroleum is expected to start full production.

### **1.3. Power Sector**

In 1998, East Timor's power sector consisted of 60 power stations with total operable capacities of 26.5 megawatts. More than half (14.7 megawatts) of these operable capacities were generated from two main power stations in Dili. The total annual electricity generation was 77 gigawatt-hours and total electricity sold was 68 gigawatt-hours. The number of customers for all power centres totalled about 43,000 (Perusahaan Listrik Negara Cabang Dili, 1998 and Asian Development Bank, 2001).

Following the violence in September 1999, 50 percent of the power stations were seriously damaged. Such destruction mainly occurred in district and sub-district centres, where power stations were driven by small capacity diesel engines with the range of 25 kilowatts to 800 kilowatts (Eletricidade De Timor Leste, 2001 and Asian Development Bank, 2001).

It is estimated that electricity demands in the territory will increase by about 5.5 percent per annum relative to the existing power supply (Eletricidade De Timor Leste, 2001). However, this estimate may only be based on the existing electricity demand, which is driven by small-scale business and residential load. If there is large-scale business investment, energy demand could exceed this annual electricity growth.

Facing poor electricity supply, the ETTA (East Timor Transitional Authority) has worked closely with numerous governments (such as Australian, Portuguese and Japanese) and the Asian Development Bank to restore power stations in East Timor. The Transitional Administration also allocated US\$11,793,000 during the period of January 2000 - March 2002 (Asian Development Bank, 2001). The restoration of the power stations will increase electricity supply back to 1999 levels. However, this increase could not cover overall energy demand, which is estimated to exceed 30 megawatts in 2002 (Eletricidade De Timor Leste, 2001).

The Asian Development Bank (2001) has programmes in place to identify the potential of rural energy resources and alternative energy sources to diesel generation. This is particularly important as East Timor faces increasing energy demand, which is in contrast with the financial ability to build new power

generation facilities. Under such circumstances, the government could increase attention to finding alternative technologies to meet energy demand and save natural resources and finances.

#### **1.4. Cogeneration System**

Conventional power generation only converts a third of primary energy input to useful energy, while a large amount of energy input is unconverted and released as “waste heat”. Cogeneration systems recover this “waste heat” leading to increased overall efficient energy use.

Cogeneration is defined as the sequential generation of electricity and useful heat from the same primary fuel, thus making use of heat that would otherwise be wasted (Taylor and Labson, 1997:1). Cogeneration systems can generate two or more useful energies (i.e. cooling, heat and power) simultaneously using a single primary energy input. Cogeneration will convert large amounts of “waste heat” from conventional power generation to produce useful energy for numerous applications such as heating and cooling for industry, buildings and food processing. It could offer potential energy savings of approximately 35% leading to operating cost saving from fuel use. The overall efficiency of cogeneration is around 80-90% (CADDET, 1995 and Hart and Rosen, 1996). Combined cooling and power also save primary energy of about 24.5% (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

In East Timor, cogeneration could be used to generate cooling for buildings and for food preservation. It could offer a reliable energy supply, primary energy (diesel) savings, transfer of technology, and job creation. Absorption cooling from a cogeneration system can be a substitute electric cooling system, which then increases the availability of electricity generated to supply other consumers. However, cogeneration systems require suitable energy demand, fuel supply and skilled people to operate and maintain them effectively. Therefore, it is necessary to determine the technical and economic viability of cogeneration applications in East Timor.

## **1.5. Project Aims and Objectives**

### **1.5.1. The Aim of the Project**

The aim of this project is to assess the applicability and economic viability of cogeneration systems to provide refrigeration and air conditioning in East Timor. The findings of the research will provide information for East Timorese decision-makers for energy planning.

### **1.5.2. The Objectives of the Study**

The objectives of this research are:

1. To undertake a literature study on cogeneration systems.
2. To assess the technical and economic viability of cogeneration systems to the cooling of food and buildings in East Timor.
3. To provide recommendations to East Timorese decision-makers regarding the suitability of adopting cogeneration systems.

## CHAPTER 2 LITERATURE REVIEW

### 2.1. The Principle of Cogeneration

#### 2.1.1. Process Description

In conventional power generation, fuel is burned in a prime mover (PM), where a third of fuel energy input will be converted in a generator (G) to produce electricity. The remaining two thirds of fuel energy input is unconverted and released as “Waste heat” (Figure 2.1). Wilkinson and Barnes (1980:3) state that even in an efficient prime mover, about two thirds of fuel input is not converted and is released unused in the exhaust gas.

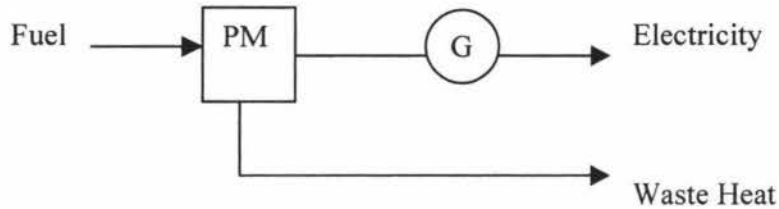


Figure 2.1. Schematic process of conventional power generation

Cogeneration is a well-established technology for generating two or more forms of useful energy (i.e. for heating, cooling and power) by using a single primary energy input. It will recover the waste heat from a conventional mover to produce useful energy such as heating and cooling for domestic, commercial and industrial applications. Figure 2.2 shows the schematic process of a typical cogeneration system.

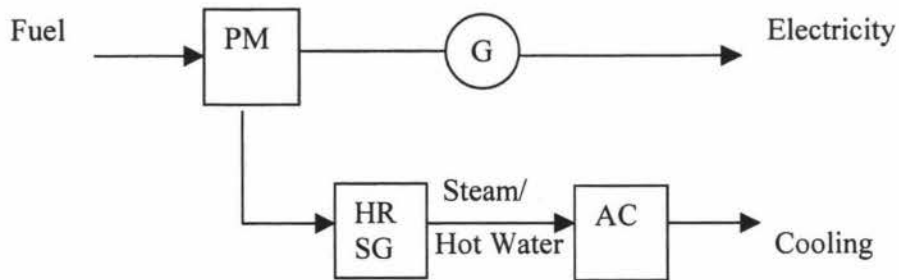


Figure 2.2. Schematic diagram of a cogeneration system

In a cogeneration system, fuel is burned in a prime mover (e.g. gas turbine, reciprocating engine or steam turbine) to produce heat, which is then converted to electricity using a generator (G). The waste heat contained in the exhaust gas is recovered in a heat recovery steam generator (HRSG), which is either a boiler or heat exchanger, to produce hot water or steam. The resulting hot water or steam is then fed to an absorption chiller (AC) where the heat energy is converted into cooling.

### **2.1.2. Benefits of Cogeneration Systems**

A number of experts, including Brown (1995), Kaarsberg and Elliot, (2000), Cogen Europe (2000) and the United States Department of Energy, (2000), have come to the conclusion that cogeneration systems can offer potential energy saving, reduction of green house gas emissions, operating cost reduction, avoidance of losses within the power transmission and distribution networks and job creation.

By converting waste heat, a cogeneration system will increase the efficiency of fuel conversion by to up to 90 percent (Kaarsberg and Elliot, 2000), with fuel savings of between 20 – 40 percent. Fuel is one important variable, which contributes significantly to the operating costs of a cogeneration system, therefore significant fuel savings also mean significant operating cost savings. Cogeneration also saves CO<sub>2</sub> emissions of up to 50% compared with conventional power generation (CADDET, 1995 and Cogen Europe, 2000). Cogeneration shifts the power generation close to the consumers, which reduces the distance required for electricity transmission. It therefore also reduces losses from power transmission and distribution (The United States Department of Energy, 2000).

## **2.2. Cogeneration Technology**

The common feature of cogeneration technology is the prime movers, which can be classified into three main types: gas turbine, steam turbine, and reciprocating engine. Each of the prime movers has advantages and disadvantages

and none of them is superior in all applications (Taylor and Labson, 1997). The optimal choice of prime movers will be dependent on energy demand, electrical load and fuel availability.

Onsite Sycom Energy Corporation (2000) mention that the choice of cogeneration technology depends on power and thermal requirements, the duty cycle, space constraints, emission regulations, fuel availability, utility prices and interconnection issues.

### 2.2.1. Reciprocating Engines

Reciprocating engines or internal combustion engines are widely used for cogeneration applications because of higher electric efficiency compared to other prime movers.

Reciprocating engines have two types: diesel engines and Otto engines. The difference between the two types of engine lies in the internal combustion system. Otto engines use an electric spark from a spark plug to ignite a fuel and air mixture introduced in the cylinder. In contrast, diesel engines compress air in the cylinder to high pressure, thus raising the temperature to the ignition temperature of the fuel, which is injected at high pressure (Onsite Sycom Energy Corporation, 1999 and United Nations Economic and Social Commission for Asia and the Pacific, 2000).

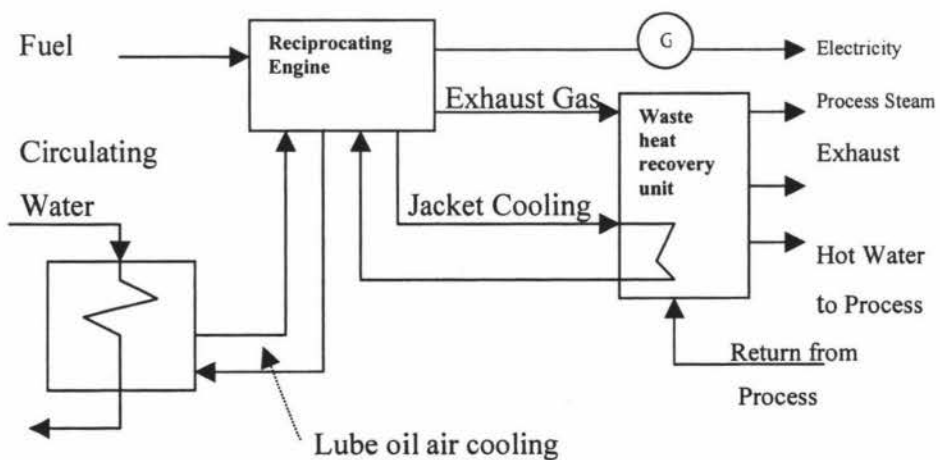


Figure 2.3. Reciprocating Engine Cogeneration System (Taylor and Labson, 1997)

Reciprocating engines can be operated using diesel, heavy fuel oil, gasoline and natural gas. The size of reciprocating engines for cogeneration applications are around 50 KW – 5,000 KW, with typical electrical efficiencies of 25 – 45% (Taylor and Labson, 1997 and Onsite Sycom Energy Corporation, 1999). Figure 2.3 shows a flow diagram of a reciprocating engine cogeneration system.

Onsite Sycom Energy Corporation (2000) claim that in reciprocating engines about 60% of the total energy input is unconverted and delivered as waste heat through the engine exhaust and jacket coolant, and in addition a small proportion is released through the lube oil cooler. The temperature of the exhaust gas and jacket water is around 55 °C - 400 °C and 55-95 °C respectively (Table 2.1). This typical waste heat can be used to drive either single or double stage absorption chillers. However, the exhaust gas cannot be totally converted into useful energy because most heat recovery units are designed to operate at exhaust outlet temperatures of 149 °C – 177 °C, to prevent the corrosive effects of condensation in the exhaust piping.

Table 2.1. Typical Temperature of Waste Heat from Reciprocating Engine

SOURCE	RECOVERABLE HEAT (% FUEL INPUT)	TEMPERATURE SOURCE (°C)
Exhaust gas	25 – 35	55 – 400
Jacket water	22 – 30	55 – 95
Lube oil	5	50 -70

Source: Taylor and Labson (1997), Onsite Sycom Energy Corporation (1999) and United Nations Economic and Social Commission for Asia and the Pacific (2000).

The typical NO<sub>2</sub> emission rate for Otto Cycle engines is around 0.5 – 2 gm/hph. This emission can be reduced to 0.15 gm/hph by using a selective catalytic reduction (SCR), in which ammonia is injected into the exhaust gas in the presence of a catalyst. However, SCR can increase the costs of installation, operating and maintenance (Onsite Sycom Energy Corporation, 1999).

The main disadvantages of reciprocating engines are high NO<sub>x</sub> emissions, noise and size limitations (Kaarsberg *et al.*, 1998). Therefore, in some

countries, the application of reciprocating engines is restricted. Nevertheless, the reciprocating engine is the leading prime mover for small-scale cogeneration systems of less than 1 MW, especially for emergency and back-up generation (The United States Department of Energy, 2000).

Reciprocating engines have typical installation costs of US\$800 - 1500/KWe (Onsite Sycom Energy Corporation, 1999 and Aspen Systems Corporation, 2000). The maintenance cost is between US\$0.01 – 0.02 / KWh (Onsite Sycom Energy Corporation, 1999 and American Electric Power, 2000).

Onsite Sycom Energy Corporation's (2000) detailed specifications and costs for numerous commercial reciprocating engines in the year 1999 and 2020 are shown in Table 2.2 and Table 2.3. The engines are specified based on the reference of the 100-KWe Caterpillar G3306 aspirated engine, an 800-KWe Caterpillar G3516 inter-cooled turbo-charged engine and a 3000-KWe G3616 inter-cooled turbo-charged engine generator set. The two larger engines have separate coolant flow to the turbochargers and have oil coolers, in which these subsystems typically cannot recover heat. Therefore, the overall efficiency of the small engine is much higher than the larger engines, although it has lower electric efficiency.

The smaller engine is much more expensive than the larger engines based on dollar per kilowatt-electricity (US\$/KWe). However, the overall installation cost for small engines is cheaper than for larger ones. The advanced engines are estimated to be much cheaper than the current engines because of the higher specific output (more power from the same block), advances in interconnecting switch-gear, more competitive pricing and experience in engineering and installation, and the impact of a developed sales and service infrastructure (Onsite Sycom Energy Corporation, 2000).

Table 2.2. Summary Cost (US\$) and Performance Specifications for Reciprocating Engine Driven Cogeneration

CHP COST AND PERFORMANCE	100 KW IC-ENG.		800 KW IC-ENG.		3,000 KW IC-ENG	
	Current	2020	Current	2020	Current	2020
Total Installed Cost (99\$/KWe)	1,390	990	975	690	850	710
Operating and Maintenance Costs (\$/kWe year)	131.2	109.3	85.2	71.0	82.7	68.9
Heat Rate (KWh/KWh)	3,554	3,266.7	3,238	2,750	3,270	2,632
Electricity Efficiency (%)	28.1	30.6	30.9	36.4	33.6	38
Thermal Energy (KWh/KWh)						
- Exhaust	0.666	0.645	0.437	0.366	0.567	0.453
- Jacket Water	0.999	0.968	0.830	0.696	0.286	0.337
Overall Efficiency (%)	75	80	70	75	62	68
Thermal Recovery Efficiency (%)	65	71	58	61	42	48
Power to Heat Ratio	0.60	0.62	0.79	0.94	1.17	1.27
Net Heat Rate (KWh/KWh)	1.472	1.250	1.655	1.422	1.911	1.645

Source: Onsite Sycom Energy Corporation (2000)

Table 2.3. Capital Cost of Reciprocating Engine Driven Cogeneration System (US\$)

COST COMPONENT	100 KW IC-ENG.		800 KW IC-ENG.		3,000 KW IC-ENG	
	Current	2020	Current	2020	Current	2020
Size (KWe)	100	100	800	800	3,000	3,000
Package Cost (\$/KWe)	550	400	430	300	380	320
Heat Recovery (\$)	100	90	75	60	65	75
Interconnect/Switchgear (\$/KWe)	150	75	60	35	35	20
Miscellaneous Equipment (\$/KWe)	70	70	50	50	50	50
Installation/Civil Work (\$/KWe)	150	100	105	70	90	70
Engineering and Management (\$/KWe)	90	60	60	40	60	40
General Contractor Mark Up (\$/KWe)	150	105	105	70	90	70
Contingencies and Guarantees (\$/KWe)	60	40	40	30	35	30
Carrying Charges During Construction (\$/KWe)	70	50	50	35	45	35
Total (\$/KWe)	1,390	990	975	690	850	710

Source: Onsite Sycom Energy Corporation (2000)

### 2.2.2. Steam Turbine

Steam turbine-generators are the oldest turbine technology and the most common type of cogeneration system for generating electricity and heat. A steam turbine is a device which converts the energy stored in steam into rotational mechanical energy. It is designed to convert steam to shaft power, which can be used to drive an alternator to produce electricity. Therefore, a boiler or heat recovery steam generator (HRSG) is required for producing steam before using it. Steam can be produced using a wide range of fuels such as coal, natural gas, fuel oil, wood, biomass, waste materials and other low cost solid fuels.

Steam turbines can be classified into two configurations, namely topping and bottoming cycle, as shown Figure 2.4 and Figure 2.5 respectively. In the topping cycle, steam from a boiler is first converted to drive shaft power and then

used to drive an alternator to produce electricity, while low pressure steam from the turbine is then used for other process applications such as heat sources for industrial processes and equipment. In the bottoming cycle, steam is first used in process applications, and the remaining steam is converted to shaft power, which is used to drive an alternator to produce electricity.

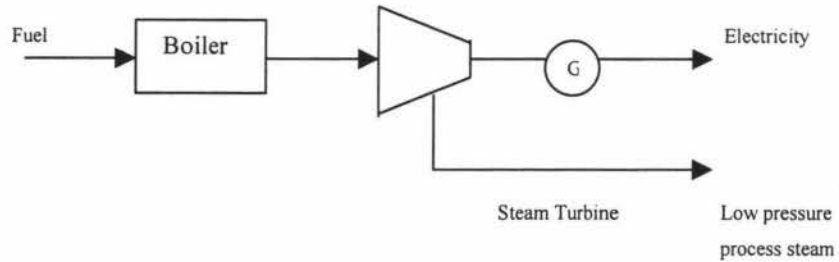


Figure 2.4. Steam Turbine Topping Cycle (Taylor and Labson, 1997)

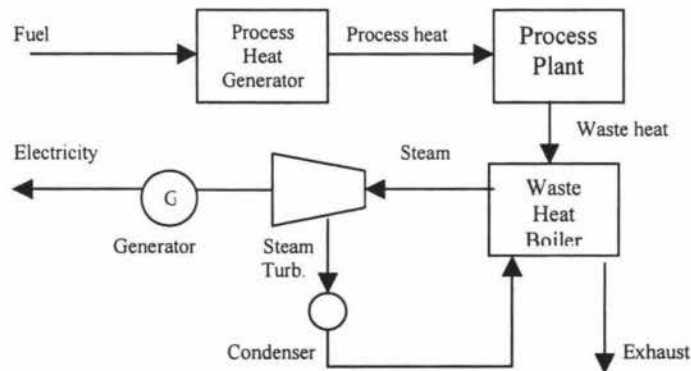


Figure 2.5. Steam turbine bottoming cycle (Taylor and Labson, 1997)

Two types of steam turbines are widely used in cogeneration plants. These are the back-pressure steam turbine and the condensing steam turbine. The main difference between these steam turbines is in the way they extract steam. In a back-pressure steam turbine cogeneration system, all the steam is expanded through the turbine without condensing, while in a condensing steam turbine cogeneration

system, steam is expanded through a condensing turbine before it is returned to the boiler (Taylor and Labson, 1997:33).

The efficiency of large condensing steam turbines for power applications, with coal as a primary energy input, is around 40-45%, while that of back-pressured turbines is 15-35 % (Taylor and Labson, 1997 and Onsite Sycom Energy Corporation, 1999). However, the overall thermal efficiency of back-pressure steam turbine cogeneration systems is about 90 percent, which is higher than the efficiency of the condensing steam turbine cogeneration system (United Nations Economic and Social Commission for Asia and the Pacific, 2000). The high thermal efficiency of back-pressure steam turbine cogeneration system is due to the fact that exhaust heat can be converted to useful energy. By contrast, the low thermal efficiency of condensing steam turbine cogeneration is because the exhaust heat cannot be used. It is normally lost in the cooling water circuit. However, the condensing steam turbine cogeneration system has higher electricity generation efficiencies. Therefore, a condensing steam turbine cogeneration system is required in places where electricity demand is higher than heat demand or the load patterns are highly fluctuating.

The capacity of steam turbines can range from a few hundred KW to over 1300 MW (Wilkinson and Barnes, 1980 and Onsite Sycom Energy Corporation, 2000). However, its low power to heat ratio and the poor match between process steam and electrical requirements become the main disadvantages of steam turbine (Taylor and Labson, 1997).

The installed costs of boiler/steam turbine power generation system are estimated to be around US\$800 - US\$1000/KWe. The additional cost of integrating a steam turbine to an existing boiler system or to a combined cycle plant is around US\$400 - US\$800/KWe (Onsite Sycom Energy Corporation, 2000 and Aspen System Corporation, 2000). However, the installed cost also depends upon site requirements such as the size of the unit, energy required and fuel characteristics (United Nations Economic and Social Commission for Asia and the Pacific, 2000). The typical maintenance cost of a steam turbine is less than US\$ 0.004 per KWh of power generated per hour (American Electric Power, 2000 and Onsite Sycom Energy Corporation, 2000).

### 2.2.3. Gas Turbine

Gas turbines are a well-established technology for cogeneration applications, especially for continuous duty. Gas turbines for continuous duty are generally classified into two groups based on their design. These designs are aeroderivative gas turbine and the industrial gas turbine (Taylor and Labson, 1997, Onsite Sycom Energy Corporation, 1999 and United Nations Economic and Social Commission for Asia and the Pacific, 2000).

Aeroderivative gas turbines are characterized by low fuel consumption, and high efficiency levels. The efficiency of a simple aeroderivative gas turbine is almost 45 percent. However, aeroderivative gas turbines require highly skilled personnel for maintenance, high quality fuel and high investment costs (Taylor and Labson, 1997 and United Nations Economic and Social Commission for Asia and the Pacific, 2000); they are also limited in capacity (Onsite Sycom Energy Corporation, 1999).

Industrial gas turbines are used for stationary and continuous operations. This type of gas turbine is generally applied to large capacity situations. The range capacity of industrial gas turbines is available from 1 MW to 250 MW. The efficiency of basic cycle of industrial gas turbine varies between 25 - 40% while the advanced cycle, which is combined cycle, has electric efficiency of approaching 60%.

Industrial gas turbines have numerous advantages compared to aeroderivative gas turbines, such as no fuel gas compressor requirement due to its lower compression ratio of 16: 1 (Onsite Sycom Energy Corporation, 1999), the fact that maintenance can be done onsite, and low investment and maintenance costs (Taylor and Labson, 1997 and United Nations Economic and Social Commission for Asia and the Pacific, 2000).

Figure 2.6 shows the diagram of a typical simple gas turbine. In this process, air in ambient condition is compressed and fed into a combustion chamber. In the combustion chamber, the high-pressured air is mixed with fuel, leading to fuel ignition. The heated combustion gas from the combustion chamber is expanded through a power turbine which is then used to drive the electric

generator (G). The residual gases are recovered in a heat recovery steam generator (HRSG) to produce heat for various applications. For larger gas turbine plants, the hot gases are recovered to produce steam for driving a steam turbine in bottoming cycle to produce electricity by using an alternator.

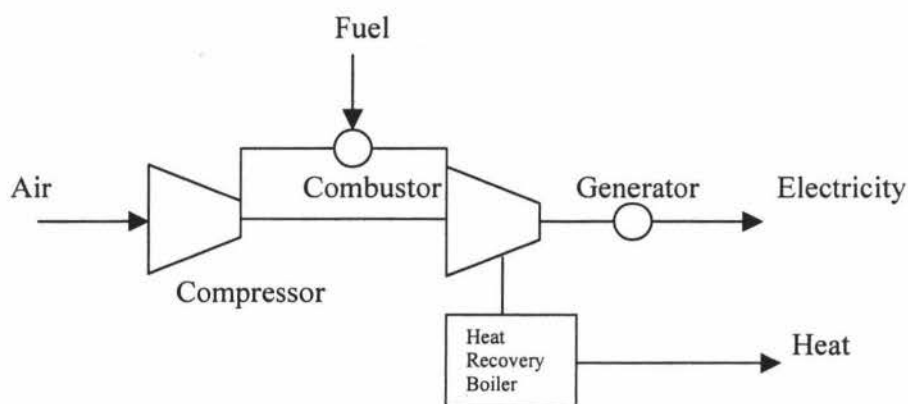


Figure 2.6. Gas Turbine Cogeneration System (Taylor and Labson, 1997)

Simple gas turbines have electric efficiencies of around 25 - 40% (Taylor and Labson, 1997 and Onsite Sycom Energy Corporation, 2000). The overall energy efficiency of gas turbine cogeneration systems is between 80 - 90%, with high-grade heat recovery which can be used to drive steam turbines and for direct heating or driving absorption chillers (CADDET, 1995).

The capital cost of gas turbine power plants on a KWe basis (US\$/KWe) can vary significantly depending on the capacity of the facility. The typical capital costs of gas turbines range between US\$300 - US\$900/KWe (Onsite Sycom Energy Corporation, 2000 and Aspen Systems Corporation, 2000). Typical maintenance costs for a gas turbine operated by natural gas is US\$0.003 - 0.005 / KWh (Onsite Sycom energy Corporation, 2000 and American Electric Power, 2000). In general, the typical operating and maintenance costs of small plants are about 4-6 percent of the investment costs, while those of plants exceeding 50 MWe are about 0.5-1.5 percent of the investment costs (Taylor and Labson, 1997).

Onsite Sycom Energy Corporation (2000:29-30) present specifications and capital costs of numerous commercial combustion turbines (CT); these are shown in Table 2.4 and Table 2.5. The specifications of current 1 MWe, 5 MWe and 10

MWe combustion turbines were based on the available commercial combustion turbines such as the Solar 1205 KW Saturn 20 gas turbine, solar Taurus 60 gas turbine and Solar Mars 100 gas turbine respectively. The specifications of the advanced systems were based on a qualitative assessment of potential efficiency improvement from the existing turbines. In particular, the 1 MWe advanced engine is based on a gas turbine (recuperation), the 5 MWe is based on the 4.2 MWe Solar Mercury 50 produced by the Department of Energy and the 10 MWe engine is based on the Mitsui SB60 (17.7 MWe) combined cycle turbine.

The capital costs were estimated based on the assumption that in the year 2020 the costs of miscellaneous equipment, materials, and labor would be reduced by 20 percent. This assumption was made based on the expectation that in future, cogeneration installation will become more streamlined and will require less onsite labor and materials. The basic costs were also calculated based on the assumption that the turbine generators package and heat recovery is expected to reduce in cost down by 10%.

Table 2.4. Summary Cost (US\$) and Performance of Combustion Turbine (CT) for Cogeneration System

CHP COST AND PERFORMANCE	1 MWe CT		5 MWe CT		10 MWe CT	
	Current	2020	Current	2020	Current	2020
Total Installed Cost (99\$/KWe)	1,600	1,340	1,075	950	965	830
Operating and Maintenance Costs (\$/KWe year)	76.8	64	46.8	39	44.3	36.92
Heat Rate (KWh/KWh)	4.572	3.627	3.627	2.815	3.444	2.654
Electricity Efficiency (%)	21.9	27.6	27.6	35.5	29	37.7
Thermal Energy (KWh/KWh)	4.572	3.627	3.627	2.815	3.444	2.654
Overall Efficiency (%)	72	73	73	74	74	74
Thermal Recovery Efficiency (%)	64	63	63	60	63	58
Power to Heat Ratio	0.436	0.607	0.607	0.92	0.646	1.041
Net Heat Rate (KWh/KWh)	1.707	1.567	1.567	1.456	1.508	1.452

Source: Onsite Sycom Energy Corporation (2000)

Table 2.5. Capital Cost (US\$) of Combustion Turbine Cogeneration System

NOMINAL TURBINE CAPACITY, KWE	1000 KWE CT		5000 KWE CT		10,000 KWE CT	
	Current	2020	Current	2020	Current	2020
Combustion Turbine	550,000	467,500	2,102,940	1,892,646	4,319,200	3,887,280
Heat Recovery Steam Generators	250,000	225,000	350,000	315,000	590,000	531,000
Water Treatment System	30,000	30,000	100,000	100,000	150,000	150,000
Electrical Equipment	150,000	120,000	375,000	300,000	625,000	500,000
Other Equipment	145,000	115,700	315,000	255,000	575,000	460,000
Total Equipment	1,125,000	958,200	3,242,940	2,862,646	6,259,200	5,528,280
Materials	143,952	115,162	356,723	285,379	688,512	550,810
Labor	347,509	278,007	908,023	726,419	1,752,576	1,402,061
Total Process Capital	1,1616,461	1,351,369	4,507,686	3,974,443	8,700,288	7,481,150
General Facilities Capital	48,483	40,541	135,231	116,233	261,009	224,435
Engineering Fees	48,483	40,541	135,231	116,233	261,009	224,435
Process Contingency	48,483	40,541	135,231	116,233	261,009	224,435
Project Contingency	171,305	143,245	477,815	421,290	922,231	793,002
Total Plant Cost	1,933,215	1,616,237	5,391,193	4,744,432	10,405,544	8,947,456
Actual Turbine Capacity (KWe)	1,205	1,205	5,007	5,007	10,798	10,798
Total Plant Cost per net KWe	1,604	1,341	1,076	948	964	829

Source: Onsite Sycam Energy Corporation (2000)

#### 2.2.4. Combined Cycle

A combined cycle cogeneration system consists of a gas turbine at the topping cycle and a steam turbine at the bottoming cycle (Figure 2.7). In this cycle, fuel is burned in a combustion turbine to produce electricity using one or more generators (G), while the waste heat in the high temperature exhaust gas is recovered in a heat recovery steam generator (HRSG) to produce steam for driving a steam turbine. Steam from the steam turbine is used to generate electricity; some of the steam could also be used to drive an absorption chiller or heat exchanger, if a site requires chilled or hot water respectively.

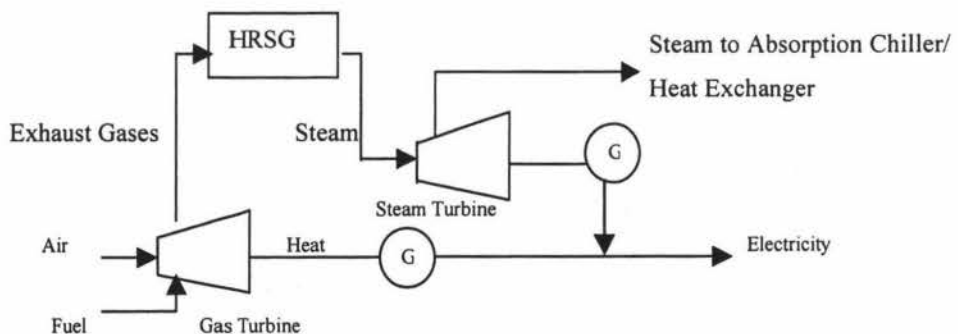


Figure 2.7. Schematic Diagram of a combined cycle cogeneration system

Currently, combined power cycle is designed to optimise the variance between electric and thermal loads. Under high electric demand situations, the combined power cycle can be designed to increase electric load by installing a steam turbine in the bottom cycle. Conversely, in the period of higher thermal energy requirement, all steam produced can be used directly for industrial processes or to drive absorption chillers.

The combined cycle cogeneration system is the best choice if an application has wide fluctuations in the amount of electricity required for industrial processes. The thermal efficiency of a small combined cycle cogeneration system is well above 40 percent (Taylor and Labson, 1997). For larger gas turbine installations, combined cycles achieve approximately 60 percent electric generation efficiencies using the most advanced utility-class gas turbines. The installation cost of a combined cycle is estimated to be US\$1200 – US\$1800 (Onsite Sycom Energy Corporation, 2000).

## **2.2.5. Absorption Chiller**

### **2.2.5.1. Principle of Absorption Cooling**

The absorption refrigeration system is a well-established technology for generating refrigeration from low-grade heat sources. If waste heat is available, an absorption chiller will become an attractive option compared to a vapour compression chiller. White and Harris (1997) state that an absorption refrigeration system will generate low costs of refrigeration where a cheap heat source is available and there are high electricity costs. Dorgan *et al.* (1995) outline a number of benefits from absorption refrigeration chillers compared to vapour compression chillers, as follows:

- i). Low electricity demand
- ii). Low noise
- iii). Utilise recovered heat to drive the systems
- iv). Less impact on global warming
- v). Economically attractive when fuel costs are less than electric costs.

### 2.2.5.2. Process Description

Figure 2.8 shows the flow diagram of a simple absorption refrigeration, consisting of four main components, i.e. absorber (A), generator (G), condenser (C) and evaporator (E). Additional components are a solution pump (SP), expansion valve (EV) and solution heat exchanger (SHX). The circulation of refrigerant in the system is as follows. Low pressure solution (LPL) from the absorber is pumped into a generator after being preheated in a heat exchanger using the returning weak solution from the generator. In the generator, the solution is boiled up using a heat source from a recovery exhaust cogeneration or direct fire so that the refrigerant and the absorbent are separated. The weak solution (high absorbent content) is returned to the absorber to absorb more refrigerant whereas the high pressured vapour (HPV) refrigerant is condensed in a condenser and then expanded across the valve before being recycled to the evaporator to complete the cycle.

The absorption refrigeration and vapour compression machines are distinguished by the energy source for driving the system. In a conventional vapour compression cycle, energy for driving the machine is electricity (Figure 2.9), while the absorption refrigeration machines require heat as the driving energy. However, an absorption chiller requires a small amount of electricity to drive the solution pump, condenser fan and cooling towers.

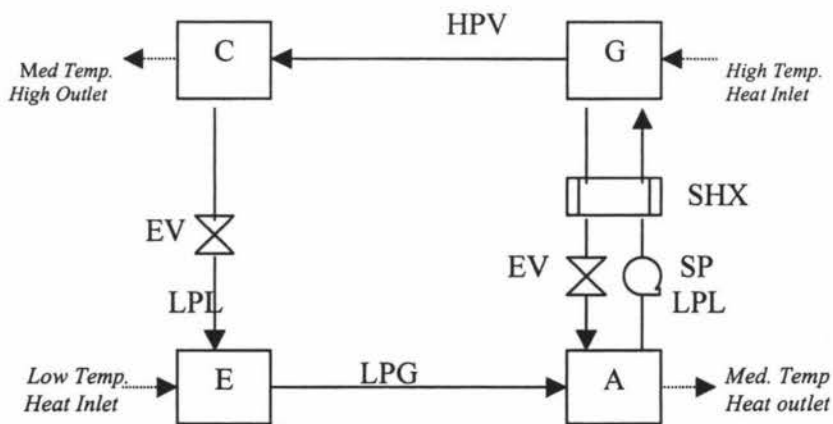


Figure 2.8. Flow diagram of a simple absorption refrigeration cycle

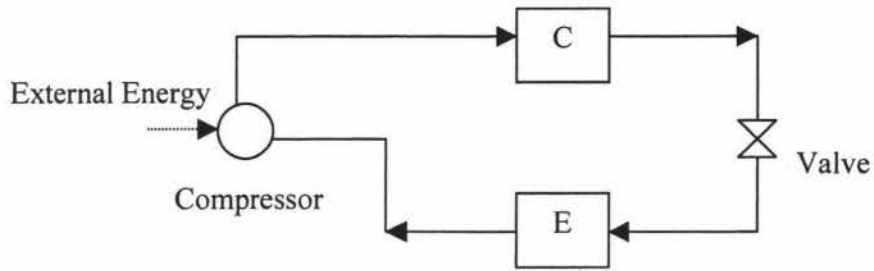


Figure 2.9. Flow diagram of a simple vapour compression refrigeration cycle

### 2.2.5.3. Working Pairs

Absorption refrigeration chillers can be distinguished based on the types of working fluid utilised in the system. A number of working fluids have been proposed for absorption refrigeration machines. However, only two working pairs have been widely used in commercial applications. These are water-lithium bromide and ammonia-water working pairs.

In a water-lithium bromide pair, water is the refrigerant and lithium bromide is the absorbent. The primary advantage of a water-lithium bromide pair is that the two fluids have different volatility, so that they can be easily separated without additional equipment. This could lead to a cost saving. However, a water-lithium bromide system cannot be operated at temperatures below 0 °C. Dorgan *et al.* (1995) state that the water-lithium bromide working pair only works efficiently for temperatures down to 6 °C. This working fluid is therefore suitable for chilling water and for air-conditioning.

In an ammonia-water system, ammonia is the refrigerant and water is the absorbent. The primary advantage of ammonia-water working fluid is that it can be operated at temperatures down to -30 °C. However, a small amount of water leaves the generator with the refrigerant so that it requires a rectifier to separate water from refrigerant in order to prevent the crystallization in the expansion valve, which then leads to reduced efficiency of the evaporator. The additional rectifier also means an increased capital cost of absorption refrigeration machines compared with water-lithium bromide machines. Ammonia is also poisonous when inhaled, meaning that ammonia gas leaks must be strenuously avoided.

#### 2.2.5.4. Number of Regenerative Stages

Absorption refrigeration machines are commercially available in both single and double stages. Currently, triple-stage absorption refrigeration cycles are also being intensively investigated and promise a high coefficient of performance. However, this type of absorption refrigeration cycle has not been successfully used due to its high temperature requirements, which the existing working fluids cannot handle.

The principle difference between single-stage and double-stage absorption chillers is the number of generators required to boil the refrigerant. A single-stage absorption refrigeration chiller uses a single generator (Figure 2.9), whereas a double-stage absorption chiller requires two generators to separate the refrigerant from the absorbent. A double-stage absorption refrigeration machine requires less cooling water compared to a single-stage absorption refrigeration machine, due to the heat condensation from a high-pressure generator, which is utilised to desorb the refrigerant from a solution in a low-pressure generator. This leads to a double-stage absorption refrigeration machine rejecting less heat per unit of cooling output, thus requiring less heat and having a higher coefficient of performance (Dorgan *et al.*, 1995).

The configuration of a triple-stage absorption chiller is similar to that of a double-stage absorption chiller. The only difference between the two chillers is in the way the absorbent solution is concentrated. In a triple-stage absorption chiller, the refrigerant solution is concentrated in three generators. The theoretical coefficient of performance (COP) of a triple-stage absorption chiller is around 1.5 – 1.65 (Dorgan *et al.*, 1995 and Hongbin *et al.*, 1999).

The high performance of the triple-stage absorption chiller is not applied commercially because a triple-stage absorption chiller requires high temperature heat (about 250 °C), which is not suitable for available working pairs (Saldanha, 2000). In reality, water-lithium bromide absorption chillers are restricted to two-stages, due to corrosion problems at temperatures over about 200 °C (Lazzarin *et al.*, 1999). Ammonia-water absorption refrigeration systems are usually restricted

to a single-stage, because the pressures reached are excessive for two-stage generators (White and Harris, 1997).

### 2.2.5.5. Performance

#### Refrigeration capacity

Dorgan *et al.* (1995) present typical temperatures of heat sources for various types of absorption refrigeration machines; these are shown in Table 2.6. This table shows that lithium bromide double-stage absorption machines require high input temperatures of 175-185 °C for steam and 155-205 °C, for hot water, while temperature inputs of single-stage absorption machines are 110-120 °C for steam and 115–150 °C for hot water. The temperature inputs of ammonia-water absorption machines for both steam and hot water are similar, being 100-195 °C.

Table 2.6. Typical Heat Input Temperature for Various Absorption Machines

ABSORPTION MACHINE	STEAM OR PROCESS GAS TEMPERATURE (°C)	HOT WATER OR PROCESS FLUID TEMPERATURE (°C)
LiBr Single-Stage	110 – 120	115 – 150
LiBr Double-Stage	175 – 185	155 – 205
AAR Refrigeration	100 – 195	100 – 195

Source: Dorgan *et al.* (1995)

White and Harris (1997) show the correlation between refrigeration capacity and temperature of heat source (Table 2.7). As presented, the lower temperature inputs would achieve low refrigeration capacity for a given chiller size. Refrigeration capacity depends on the temperature of the heat source supplied to the generator. For instance, reducing the temperature of heat source from 118 °C to 90 °C will reduce the refrigeration capacity by about 51 percent. The higher the temperature of the heat source, the higher the refrigeration capacity.

Table 2.7. Variation of Capacity with Heat Source Temperature in a Nominal 370 kW Absorption Chiller

HEAT SOURCE	REFRIGERATION CAPACITY (KW)
2 bar (118 °C) steam	370
0.14 bar steam	270
90.6 °C water exiting at 95 °C	180

Source: White and Harris (1997)

### Coefficient of Performance

The coefficient of performance (COP) is defined as the ratio of useful energy gained from an absorption-cooling machine to the energy input. This definition is expressed in equation 2.1.

$$\text{COP} = \frac{Q_E}{Q_{\text{Gen}}} \quad 2.1.$$

Where COP = Coefficient of performance

$Q_E$  = Useful cooling gained from evaporator

$Q_{\text{Gen}}$  = Heat input in generator/desorber

A typical COP of a lithium bromide single-stage absorption machine is 0.6- 0.7, while for a double-stage it is 0.9 – 1.2 (Dorgan *et al.*, 1995). This typical COP is almost the same as that quoted by Kaarsberg *et al.* (1998) of about 0.7 and 1.1 for the temperature range between 100-120 °C and 150-170 °C respectively. As a rule of thumb, White and Harris (1997) set the COP of a single stage-water-lithium bromide absorption machine as 0.65 and the COP of a double-stage water lithium bromide absorption machine as 1.05.

The COP of vapour compression machines range from 2 – 5. This COP is higher than the COP of a double-stage absorption refrigeration machine; however, care must be taken in comparing these types of refrigeration machines. It is true that the COP of an absorption refrigeration machines has a low COP, but absorption refrigeration machines require heat as an energy source while compression refrigeration machines require electricity. Heat has lower economic

value than electricity, and under certain conditions, is of no value at all. In such circumstances, heat can be ignored from the cost calculation (White and Harris, 1997). Furlong (1994) mentions that if the electricity price is high (in \$/KWt), then the absorption chiller will have an advantage in operating costs.

### Economics of Absorption Chillers

The total cost of absorption refrigeration system comprises initial costs, operation and maintenance. It is complex to determine costs of an absorption system; therefore for the purpose of this study, all costs are based on Dorgan *et al.* (1995).

Investment costs include costs of the absorption machine, heat rejection and recovery equipment and auxiliary equipment. However, different systems have different costs. Table 2.8 and Table 2.9 show the typical capital costs of an absorption machine and cooling tower respectively. Smith (1994) estimates that heat recovery costs are around US\$ 33 to US\$ 88 kg/h of steam. Dorgan *et al.* (1995) suggest using US\$55 kg/h of steam for calculations.

Table 2.8. Typical Capital Costs (US\$) of Various Sizes and Types of Absorption Chiller

SIZE (KW <sub>T</sub> )	SINGLE-STAGE (\$/KW <sub>T</sub> )	DOUBLE-STAGE (\$/KW <sub>T</sub> )	AQUEOUS AMMONIA (\$/KW <sub>T</sub> )
900	95 – 190	130 – 260	340
1750	65 – 140	90 – 195	340
3500	60 – 110	80 – 155	Not available
5300	55 – 110	80 – 150	Not available

Source: Dorgan *et al.* (1995)

Table 2.9. Costs of Cooling Towers for Absorption Systems

COOLING WATER TEMPERATURE DIFFERENCE (°C)	TYPE OF COOLING TOWER	SINGLE-STAGE CHILLER (US\$/KW <sub>T</sub> )	DOUBLE-STAGE CHILLER (US\$/KW <sub>T</sub> )
6	Centrifugal Propeller	70	63
		68	60
8	Centrifugal Propeller	63	57
		61	55
11	Centrifugal Propeller	60	54
		58	53

Source: Dorgan *et al.* (1995)

Operating costs include energy use for the absorption machine and electricity usage for the cooling water pump and tower fan. Table 2.10 shows the typical requirements of electricity consumption for absorption refrigeration machines.

Table 2.10. Absorption Machine Electric Use

MACHINE TYPE	MACHINE SIZE (KW <sub>T</sub> )	ELECTRICAL USE (KW/KW <sub>T</sub> )
Single-Stage	350 – 700	0.009
	700 – 1400	0.006
	1400 – 2100	0.004
	2100 – 3500	0.003
	3500 – 5600	0.003
Double-Stage	350 – 900	0.006
	900 – 1600	0.006
	1600 – 2800	0.005
	2800 – 5300	0.004

Sources: Dorgan *et al.* (1995)

### 2.2.5.6. Trigeneration

#### Process Description

Trigeneration is a cogeneration technology, which produces heat, cooling and power simultaneously using a single primary fuel input. The process description of a trigeneration system driven by a gas turbine at topping cycle can be seen in Figure 2.10. In this process, fuel is burned in a combustion chamber to produce heat. Heat from the burning fuel is transformed to mechanical energy

using a turbine, and ultimately converted to electricity using a generator. High-pressure hot gases from the gas turbine are recovered to produce steam by using a boiler or heat recovery steam generator (HRSG); this steam is then used to drive a steam turbine for generating electricity at bottoming cycle. Low-pressure steam from the steam turbine can be used to drive a heat exchanger to produce hot water and an absorption chiller to produce chilled water. Some steam from the steam turbine can be directly used for heating in food processing and industrial equipment.

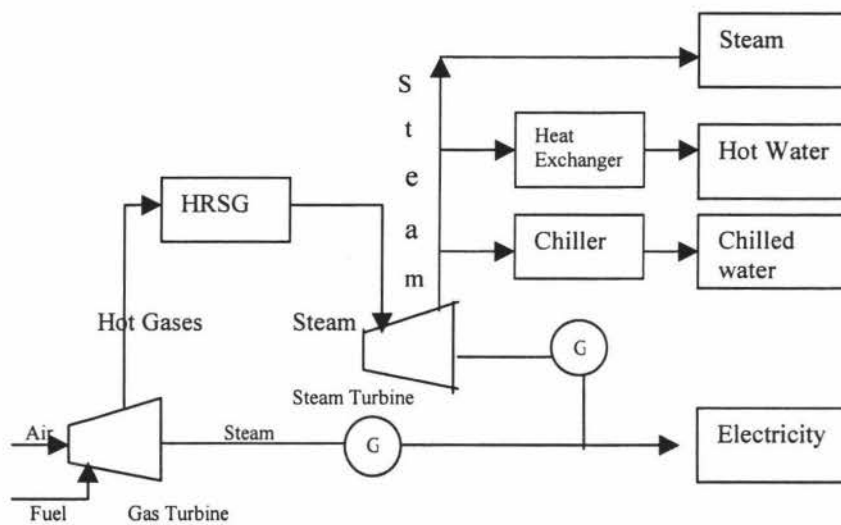


Figure 2.10. Flow diagram of a gas turbine based trigeneration facility (United Nations Economic and Social Commission for Asia and the Pacific, 2000)

Trigeneration technology provides greater flexibility at sites with demand for energy in the form of heat and cooling, creating much better use of energy resources. This advanced technology can be used to provide cooling for various applications such as cooling of food, buildings and industrial equipment. In regions with extremes of hot and cold weather, trigeneration technology is applied to provide cooling for buildings in summer, while in winter it can provide hot water and heating. In tropical countries, trigeneration can be used to provide cooling for food preservation and buildings.

## **2.3. Barriers for Cogeneration Applications**

Cogeneration technology offers potential energy saving and reduction of gas emissions, which in turn leads to cost savings. However, cogeneration systems are not adopted widely due to a number of main obstacles: technical, institutional, opposition from grid utilities and financial barriers. These barriers do not coexist in all countries but may vary from one country to another based on their specific problems. In some countries, lack of experts, technology and finance is a barrier, while others face limitations of fuel supply and lack of a regulatory framework.

### **2.3.1. Technical Barriers**

A key technical challenge is matching electricity loads against heating/cooling loads at all times. Therefore, many potential cogenerations are dismayed by perceived technical difficulties of cogeneration. They see cogeneration systems as more complex than their current technology, although external skilled staff can fill the gap of unavailability of internal skilled staffs to handle cogeneration. This technical barrier could be further increased by the unwillingness/incapability of potential cogenerators to take risk for operating new technology because cogeneration systems require time, finance and skilled technicians compared to conventional technology (Kingston Renolds Thom and Allardice Limited (1988)).

Other common technical barriers are lack of awareness of cogeneration benefits, limited availability of skilled people, and unavailability of cogeneration technologies and supporting infrastructures in some countries (Kingston Renolds Thom and Allardice Limited, 1988, Elliot and Spurr, 1999, United Nations Economic and Social Commission for Asia and the Pacific, 2000, Cogen Europe, 2000 and the United States Department of Energy, 2000).

Unavailability of local manufacturing companies to produce cogeneration equipment locally also becomes a potential technical obstacle for cogeneration. A cogeneration system that relies on importing technologies will not only increase the cost of investment and maintenance, but also potentially delay the operation of the company as a result of trouble-shooting. In many developing countries, this will be hindered by the limitation of technical experts to design, build, operate

and maintain cogeneration systems (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

Lack of supporting infrastructures could also affect the adoption of cogeneration systems. In many cases, the potential cogeneration system such as gas turbine cannot be adopted due to lack of infrastructures, i.e. gas networking and distribution. In Europe, for example, Portugal and Greece have no gas network supplies to support cogeneration systems (Cogen Europe, 2000), while Indonesia, one of the biggest natural gas producers, has inadequate gas networks and distribution capacity.

### **2.3.2. Financial Barriers**

The major economic constraints are that cogeneration systems require high initial capital investment costs, potential investors lack confidence that they will obtain an adequate return on investment in the longer term. In volatile economic conditions, investors are willing to invest in sectors, which can accurately predict benefits at certain periods, rather than dealing with uncertainty. This is particularly true when fuel and electricity prices, the key parameters for cogeneration viability, are unstable, particularly where no regulatory framework is in place to control energy prices.

Cogeneration can also be unattractive for private sectors in countries where electricity and fuel prices are heavily subsidized (United Nations Economic and Social Commission for Asia and the Pacific, 2000). Unrealistic energy prices will hinder cogeneration applications because it will be difficult to predict the capital costs and financial benefits. Therefore, investors require reduction and stability of fuel prices, investment subsidies, tax benefits and attractive tariffs.

High investment costs and uncertainty of return on investment costs have hindered cogeneration application in underdeveloped countries because they have financial limitations locally, despite the fact that cogeneration systems can offer energy and cost savings as well as increased reliability of energy supply.

### **2.3.3. Institutional Barriers**

The principle institutional barrier is the lack of concern of governments in dealing with energy and regulation issues. Establishing a promotional organisation for cogeneration will help to provide a policy framework and develop a cogeneration market. Unfortunately, some developing countries have inadequate institutions to deal with energy and environmental issues (United Nations Economic and Social Commission for Asia and the Pacific, 2000). Due to a paucity of promotional institutions for cogeneration, there are insufficient energy conservation campaigns which distribute information on cogeneration

Institutional barriers occur not only in developing countries but also in developed countries. In the USA, for instance, the environmental permit system for cogeneration is complex, costly, time consuming and uncertain; as well, current regulations have not recognised the overall energy efficiency of CHP, nor do they credit the CO<sub>2</sub> emissions saved from displaced grid electricity generation (Elliot and Spurr, 1999). This can be seen in the case of Massachusetts Institute of Technology and Malden Mills Industries (Kaarsberg and Elliot, 2000). In 1985, Massachusetts Institute of Technology (MIT) decided to generate its own electricity because of the increase in electricity costs, poor electricity supply from the local utility and the contribution of the university's boiler (for heating and cooling supply) to local air pollution. MIT wanted to install a 22 MW combustion turbine using natural gas as a primary fuel to meet 94% of the institute's power, heating and cooling demands. This would reduce the annual energy budget by 40%. However, the institute's plan failed to meet NO emissions proposed by the State Government, although their experts argued that their cogeneration system would reduce annual pollutant emissions by 45%. To meet emission standards, the State Government recommended use of approved technology, which would be more expensive and also pose a potential health risk due to the use of large amounts of ammonia in the heart of the university. Subsequently, MIT appealed the State decision and won by demonstrating that the gas emissions from their cogeneration system were lower than that of the State's approved technology. MIT also faced obstacles from the local utility, CelCo, who demanded that MIT pay daily compensation of US\$3,500 (US\$1.3 Million per year) for leaving the Grid Utility. This demand was approved by the Massachusetts Department of

Public Utilities. MIT appealed to the Supreme Judicial Court, and the Court ruled to reverse the decision of the Department of Public Utility.

Malden Mills Industries is a textile plant, which faced similar problems to MIT when they proposed to build a cogeneration system. They faced obstacles in getting environment permits, and strong opposition from the local grid utility. Although Malden Mills succeeded, it required time, energy and finance (Kaarsberg and Elliot, 2000).

#### **2.3.4. Opposition from Electricity Utilities**

In many countries, electricity generation and its networking are a monopoly of either state or multi-national companies, which have created an uncompetitive market for alternative energy. Grid utility authorities consider cogeneration as having the potential to reduce their revenues; therefore, they reject cogeneration proposals. By contrast, if electricity utilities accept cogeneration proposals, they will charge high tariffs for stand-by and pay low electricity buy-back rates. According to Aspen Systems Corporation (2000), the high tariffs of back-up and low rates for electricity buy-back could severely delay a new cogeneration project or even terminate the project altogether because it contributes to onsite generation being economically unfeasible.

### **2.4. Policy for Cogeneration Promotion**

There is evidence that carbon dioxide and other greenhouse gas emissions have potentially contributed to climate change and ozone layer depletion, leading to an increased threat to the environment, the economy and social life. Concerning these consequences, 38 industrialised countries have agreed to reduce their greenhouse gas emissions starting in 2008-2012 as stated in the Kyoto Protocol (Geller *et al.*, 1998). Following the Kyoto Protocol, many developed countries have committed to find and promote alternative technologies including energy technology as a substitute for inefficient energy use and to reduce high greenhouse gas emissions.

To reduce CO<sub>2</sub> emissions, Geller *et al.* (1998) suggest the promotion of cogeneration systems by removing all cogeneration barriers, providing expedited

permission for cogeneration systems, implementing output-based air pollution regulation and establishing a standard depreciation period of seven years for all new cogeneration facilities.

Additional programs to promote cogeneration systems include dissemination programs for cogeneration systems through briefing materials, brochures, case studies, demonstration projects and technical assistance. They also include initiation of research and development activities to expand the range of cogeneration technologies especially for small-scale cogeneration systems, power sector deregulation, investment tax credits, and fair electricity stand-by and buy back (Elliot and Spurr, 1999 and Laitner *et al.*, 2000).

In the United Kingdom, one of the leading countries for cogeneration applications in Europe, the government has been extensively involved in the promotion of clean and efficient technology. Such commitment can be seen from the government policy to increase the contribution of cogeneration systems to power generation, and also the application of a carbon tax. To achieve this, the government has involved itself in activities such as dissemination programs, demonstration projects, liberalisation of gas and electricity markets and relaxation of the electricity licensing regime (The United Kingdom Department of Environment and Combined Heat and Power Association, 1996). Relaxation of electricity licensing includes allowing cogeneration owners to export their extra power of up to 500 KWe, without the need of supply licensees.

Promoting cogeneration systems in developing countries is different from promotion in developed countries. In developed countries, technology, experts, infrastructure and finance are generally available; therefore, they only concentrate on developing sound policies for attracting investors to cogeneration systems. On the other hand, developing countries not only face a lack of policy frameworks, insufficient experts and technology, but also a lack of local financial resources which could hinder the adoption of cogeneration technology. Thus, developed countries should provide financial, expert and technologic assistance (Roy-Aikins, 1994 and United Nations Economic and Social Commission for Asia and the Pacific, 2000).

## **2.5. Cogeneration Systems in Developing Countries**

### **2.5.1. Potency of Cogeneration Applications**

Cogeneration systems are not a new technology in many developing countries. Thailand, Malaysia, India, Bangladesh, Indonesia and Brazil have adopted cogeneration systems for various applications such as petro-chemical industries, sugar processing, hotels, textile mills, paper mills, palm oil mills, and food and beverage industries (United Nations Economic and Social Commission for Asia and the Pacific, 2000, Natu, 2000 and Cogen, 2001). Sugar mills generate residues such as bagasse, which can be used for heat and power. According to the United Nations Economic and Social Commission for Asia and the Pacific (2000), processing one tonne of sugarcane will generally produce an average of 300-kg bagasse.

Table 2.11 shows cogeneration capacities in selected developing countries. In Thailand, there are 20 industrial estates that use cogeneration; together they produce about 5,000 MW. In the Philippines, the stand-by generating capacity of industries is estimated to be 600 MW, 58 percent of which operates in cogeneration mode (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

In Indonesia, cogeneration systems have been used in sugar plants since the 1920s, refineries since the 1950s and fertilizer plants since the 1970s. According to Akmal and Herman (1999), cogeneration systems have been adopted by a number of industries such as fertilizer plants (Iskandar Muda, Pusri), sugar plants (Madu Baru, Gula Putih Mataram), paper mills (Kertas Kraft Aceh and Tjiwi Kimia) and wood industries. The total installation capacity of cogeneration in Indonesia is 2,953 MW, which generates 10,676 GWh of energy per annum (Sasongko and Santosa, 1999).

In India, a national survey carried out in 2000 estimated that the overall capacity of industrial cogeneration systems is around 15,000 MW, with a third of this capacity being derived from sugar mills (United Nations Economic and Social Commission for Asia and the Pacific, 2000). The government has committed itself to build 60 new sugar mill cogeneration plants in Maharashtra, India by 2005 (Natu, 2000).

Table 2.11. Cogeneration Capacity in Selected Developing Countries

COUNTRY	COGENERATION CAPACITY (MW)
Bangladesh	979
Brazil	12,628
Egypt	1,070
India	15,000
Indonesia	2,953
Philippines	400
Thailand	5,000

Source: Sasongko and Santosa (1999), Khozam (2000), United Nations Economic and Social Commission for Asia and the Pacific (2000) and De Hollanda and Fyodorova (2000).

### 2.5.2. Policy for Cogeneration Promotion in Developing Countries

A renaissance of cogeneration systems is occurring in developing countries because of two factors: increasing energy demands for economic growth; and limited financial resources to build new power generation. On the other hand, it is hindered by the increase in the price of fossil fuel in international markets.

In Asian countries, the economic downturns have decreased the financial capacity of governments to build new power generation plants. To sustain energy supply, many developing countries such as Indonesia, India, Thailand and the Philippines have started to deregulate the power sector in order to encourage the private sector to participate in building new power supply systems including cogeneration ones (Forsyth, 1998 and United Nations Economic and Social Commission for Asia and the Pacific, 2000). Subsequently, they also established policy frameworks to promote cogeneration systems via dissemination programs, financial incentives and allowing electric generation from private sectors to supply to the government grid (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

In Thailand, for example, in 1988 the government encouraged the private sector to become involved in power generation via cogeneration, and in renewable energy, including allowing them to sell generated power to consumers, if the customer is not connected to the grid. Following this government encouragement, the private sector has requested to establish cogeneration plants

totaling 300 MW (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

In India, the government has issued guidelines to fix electric tariffs by cogenerators. This also includes allowing potential cogenerators to develop their own cogeneration facilities without the need to follow a bidding process. The government also provides financial assistance such as subsidies, low cost loans and technical assistance (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

In the Philippines, the government provided a policy framework via Executive Order No 215 year 1987 in order to allow the private sector to participate in the power sector including cogeneration. The Government also prepared dissemination programs for cogeneration systems as well as providing fiscal incentives such as an income tax holiday for six years, duty reduction of 3% for imported capital equipment and spare parts, tax credit on domestic capital equipment and spare parts, and a tax deduction for labour expenses (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

Promoting cogeneration systems in developing countries will also require assistance from developed countries in the form of finance, experts and technology in order to increase developing country capacity to handle novel clean technology. Developed countries could also assist in formulating national strategies and policy frameworks to meet energy efficiency targets and introduction of energy efficiency measures.

Financial assistance in the energy sector has traditionally been through official development assistance with a project approach. Forsyth (1998) suggests that it could be carried out not only on a project basis but also in other ways, such as:

- (1). International equity investment in local stock exchanges;
- (2). International mutual funds specializing in sustainable development through providing soft loans with long repayment periods and offering direct ways to invest in local equity markets;

(3). Debt finance; little of this has gone to renewable energy, with the exception of some new venture capital funds being channeled into new energy through the international finance corporation (IFC);

(4). International aid from multilateral lending agencies;

However, funding alternative technology through a lending approach could also increase the vulnerability of developing countries if developed countries have no goodwill to promote the transfer of technology and to assist in developing human resources in developing countries to handle the new technology.

### **2.5.3. Case Studies**

The following three case studies from Malaysia and Thailand are intended primarily to show that cogeneration systems are well accepted in many developing countries. All three sites use steam turbine generation systems with biomass as primary energy inputs. All combine heat and power generation.

Combined cooling and power cogeneration is found in developing countries, for instance in Putra Jaya Government Administration Center and Kuala Lumpur International Airport in Malaysia. However good descriptions of these are difficult to obtain; hence no case studies of combined cooling systems are presented here.

While cogeneration systems could well be implemented in East Timor in future, this (the author's) country as yet has no such systems.

#### **2.5.3.1. Wood Waste for a 1.65 MW Power Plant in Malaysia**

This 1.65 MW power plant is located in Tanjung Manis, Sarikei, Sarawak (Malaysia) and belongs to Homet Raya Sdn. Bhd., a member of the Rimbunan Hijau Group, one of the biggest wood industries in Sarawak, Malaysia. The company has 5 sawmills, 3 ply mills and 2 laminated board plants. Besides producing plywood, this company also manufactures veneer, particleboard and furniture.

The goal of this cogeneration system is to cover all energy demands i.e. power and steam, and avoid environmental damage from wood residues. Power is supplied to the mill, while steam is used for kiln drying. Wood residues from the company are recycled and used to fire the boiler. The plant employs an automatic feeding system, a boiler with a capacity of 30 tonnes per hour of saturated steam at 22 bar, a fully condensing turbo-generator (1.65 MWe) and a flue gas cleaning system. Twenty tonnes of steam are used for power production while ten tonnes are delivered to the kiln drier.

The total capital cost amounted to US\$ 1,994,000 and the pay-back time of the project is expected to be around 3 years.

#### **2.5.3.2. Cogeneration in a Palm Oil Mill (Malaysia)**

Malaysia is one of the biggest palm oil exporting countries, with 64 percent of the world market in 1995. The huge amount of process wastes from palm industries causes environmental problems. The Kilang Sawit United Bell Sdn. Bhd, a company under Bell Group, which is involved in palm oil extraction, acknowledges the legal and environmental implications of their business if they continue to use their traditional methods to dispose of oil palm wastes; they therefore decided to install a cogeneration system (Cogen, 2001).

The cogeneration plant is located in Pontian, Johore (Malaysia), about 100 km northwest of Singapore. It consists of a water tube boiler generating 35 tonnes of steam/hr at 23 bar, and a 1200 KW back-pressure turbo-generator. The total investment costs amount to US\$ 676,262, excluding civil works and building foundations (Cogen, 2001).

By producing self-power supply, the company is expected to save energy of around US\$ 519,221 per year, compared to the normal electricity consumption from the grid. The expected pay-back period is less than 3 years after commissioning (Cogen, 2001).

#### **2.5.3.3. Rice Mill Cogeneration Plant in Thailand**

Rice husks produced as residues from rice milling can be used as fuel. In a typical rice mill, electricity required for milling is purchased, and the heat needed

for either mechanical paddy drying or for parboiling is generated from fossil fuels or rice husks. Every tonne of paddy processed generates around 250 kg of husk, which can be used as fuel for a boiler to drive a generator to produce about 100 KWh of electricity (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

One of the rice mill cogeneration plants is the Chia Meng plant, which is located in Chakkaraj, Nakorn Ratchasim, Thailand. Chia Meng is one of the biggest rice mills in Thailand and has a milling capacity of 500 tonnes of paddy per day. The company decided to build a 2.5 MW cogeneration plant to increase reliability of electricity supply, steam self-supply and avoid environmental damage caused by huge wastes from rice husks. The plant was commissioned in March 1997 and consists of:

- A rice husk storage, conveying and automatic boiler feeding system;
- A furnace/boiler producing 17 tonnes of superheated steam at 35 bar and equipped with an automatic ash removal system;
- A 2.5 MW multistage fully condensing turbo-generator with condenser;
- Heat exchangers using boiler flue gas and/or superheated steam to generate hot water for paddy dryers.

The total investment costs amounted to US\$ 3,930,000 excluding civil works and building structures. The revenues from electricity and rice husk disposal savings and from excess power sales could reach US\$ 994,494 per year. Additional income from ash sales amounts to US\$ 304,035. The payback time of this project is expected to be shorter than 4 years after implementation of the plant (Cogen, 2001).

## **CHAPTER 3**

### **POTENTIAL APPLICATION OF COGENERATION IN EAST TIMOR**

#### **3.1. Cooling**

Cooling is used for multiple purposes, such as comfort, food preservation and industrial processing. In East Timor at present, cooling is used for two main applications: food preservation and comfort.

##### **3.1.1. Food Preservation**

Cooling can keep food in a condition closely resembling its fresh state, and freezing under carefully controlled conditions can ensure that loss is relatively slow (Cleland, 1990:1). Cooling and refrigeration can slow the growth of bacteria, because in general, bacteria grow most rapidly in the temperature range of 5 ° C to 60 ° C. Thus a refrigerator set at 5 ° C or below will allow most food to be stored for longer than is otherwise possible.

As a tropical country, East Timor requires cooling to preserve food. It is estimated that food production will increase compared to the previous years. Increasing food production will require markets and good food storage. Poor market availability could discourage farmers from boosting food production. However, selling food without good storage could also potentially cause huge financial losses for the sellers. This is particularly true because high ambient temperature will quickly cause food quality to deteriorate.

In East Timor, food produced is mainly marketed in Dili. Most food is transported and sold in Dili without good storage. For instance, most fish are transported and sold without refrigeration; therefore, their quality drops rapidly in the high ambient temperature, and fish can only be stored for one day. Ideally, there should be a refrigeration system to extend the time of food storage. This should lead to reduced financial losses due to the degradation of food quality caused by high ambient temperature. By preventing the growth of bacteria, refrigeration can also reduce the incidence of illness. Unfortunately, refrigeration cannot be used in the near future because of high capital and operating costs,

which are not affordable to most local people. In fact, in East Timor, there is at present only one mini-market (Hello Mister) selling refrigerated food, using 8 refrigerators.

### **3.1.2. Cooling for Buildings**

Demand for cooling for comfort is low in East Timor since a large number of people still live in poverty, and cannot afford it. However, numerous buildings have installed air conditioning systems. These buildings include government offices, hospitals and university, bank, hotels and mini market.

Cooling installation is concentrated in Dili because Dili is the capital city where most government and business activities take place and where 90% of the international community is located. Consequently, there is rapid economic growth there. By contrast, districts and sub-districts are characterized by a high degree of poverty, poor infrastructure and poor power supply. Poor power supply, both in terms of operable capacity and operational time, also discourage installation of cooling in districts and sub-districts.

For instance, Dili has 24 hours of electricity supply, while many districts obtain daily electricity supply of only 17 hours. Many sub-districts only get 12 hours of electricity supply, from 6PM to 6AM. Ideally, there should be continuous 24 hours electricity supply to encourage some local villagers to install cooling systems for small-scale businesses, such as a simple motel with air conditioning, ice for cooling food and much more.

Although numerous buildings install cooling systems, each building has cooling capacity below 100 kilowatts, except UNTAET Building with 269.5 kilowatts generated from 110 air conditioners. In addition, installed cooling capacity may not reflect the real cooling consumption. In general, air-conditioned rooms have an installed thermostat to keep temperature constant during the change of ambient temperature. Therefore, cooling consumption may be above or below the installed cooling capacities. This is particularly true for East Timor, where air conditioning capacity is usually based on guesswork rather than calculation.

Low cooling demand will not enable the installation of an expensive absorption cooling system in a single building. If an absorption cooling system is installed in a site with low cooling demand, it will potentially lead to high capital and operating costs compared to a site using an electric cooling system. To attain enough cooling demand to make cogeneration viable, a number of buildings in the one area could be grouped based on cooling load.

### **3.1.3. Cooling Load**

East Timor currently has few cooling applications in food preservation areas. For example, the mini market Hello Mister is currently the largest food supermarket in East Timor, but the supermarket only employs 8 refrigerators for cooling of food. The total cooling capacities of these refrigerators are 28 kilowatts of refrigeration (based on the installed capacity from manufacture). It would be financially unwise to install an expensive ammonia-water refrigeration machine for such a light cooling load. For such loads, it is better to use electric refrigerators.

### **3.1.4. Cooling load calculations**

In the rest of this chapter we consider how the total cooling load of a selected set of buildings in Dili could be calculated. The results of these calculations are presented in chapter 4.

These calculations of cooling demands are based on heat loads using the room by room approach. The room-by-room approach requires specification of all parameters such as room dimensions, insulation, air infiltration, personnel, light fixtures and environmental conditions (i.e. ambient temperature, air velocity and humidity). Although it requires many parameters, the room-by-room approach provides a good estimation for time variable heat load (Lovatt, 1992, Kallu, 1993 and White and Harris, 1997).

Cleland and Cleland (1992) defined heat load as the amount of heat that must be removed through the evaporator of a refrigeration system. The total heat loads in chillers, freezers, cool stores and cold stores can be calculated using equation 3.1. This equation takes into account factors such as product and

packaging, fans, lights, mechanical devices, people, heat infiltration through surfaces, air interchanges, cooling of room structures, product weight loss and defrost loads.

$$\varnothing_{tot} = \varnothing_p + \varnothing_{pk} + \varnothing_f + \varnothing_l + \varnothing_{md} + \varnothing_{pe} + \varnothing_i + \varnothing_a + \varnothing_{st} + \varnothing_d \quad 3.1$$

- Where  $\varnothing_{tot}$  = total heat load (W)  
 $\varnothing_p$  = product load (W)  
 $\varnothing_{pk}$  = packaging load (W)  
 $\varnothing_f$  = fan load (W)  
 $\varnothing_l$  = Lighting load (W)  
 $\varnothing_{pe}$  = people load (W)  
 $\varnothing_I$  = surface heat infiltration load (W)  
 $\varnothing_a$  = air interchange load (W)  
 $\varnothing_{st}$  = cooling of structures load (W)  
 $\varnothing_d$  = load due to defrost (W)

In air-conditioned rooms for comfort, equation 3.1 should be simplified to reflect the real heat loads. Kallu (1993) noted that to model the heat loads of air conditioning for comfort rooms, it is important to consider parameters such as insulation, air interchange, fan power, hot water use, lighting and people loads while products loads are ignored. However, for the purpose of this study fan and insulation loads were not included because all selected buildings in East Timor are concrete buildings without insulation and fans. Therefore, equation 3.1 was modified to calculate heat loads as below:

$$\varnothing_{tot} = \varnothing_l + \varnothing_a + \varnothing_{pe} + \varnothing_i \quad 3.2$$

- Where  $\varnothing_{tot}$  = total heat load (W)  
 $\varnothing_l$  = lighting load (W)  
 $\varnothing_{pe}$  = people load (W)  
 $\varnothing_I$  = surface heat infiltration load (W)  
 $\varnothing_a$  = air interchange load (W)

### a. Surface Heat Infiltration Load

Heat infiltration is defined as heat entering an air-conditioned area through the walls, roof, and closed doors and windows by heat conduction; it does not include the heat load due to doors openings (Cleland and Cleland 1992). In particular, surface infiltration loads consist of ceiling, wall, floor, door and window loads.

#### (1). Wall Loads

Heat infiltration through walls was calculated using equation 3.3.

$$\dot{Q}_i = UA (T_{amb} - T_i) \quad 3.3$$

Where  $\dot{Q}_i$  = heat infiltration load through wall (W)

$U$  = overall heat transfer coefficient ( $W/m^2.K$ )

$A$  = Wall area ( $m^2$ )

$T_{amb}$  = ambient temperature ( $^{\circ}C$ )

$T_i$  = inside room temperature ( $^{\circ}C$ )

The overall heat transfer coefficient ( $U$ ) for insulated and uninsulated walls can be calculated using equation 3.4 and equation 3.5 respectively. However, as the buildings being studied are concrete ones, equation 3.5 was used to calculate the overall heat transfer of coefficient ( $U$ ). Insulation factor ( $E$ ) and thermal conductivity ( $k_i$ ) are 1 and  $1.1 W/m^2.K$  (concrete) respectively.

$$U = \frac{k_i}{x_i} E \quad 3.4$$

$$U = \frac{1}{\frac{1}{h_o} + \frac{x_i}{k_i E} + \frac{1}{h_i}} \quad 3.5$$

Where  $h_o$  = outside convective heat transfer coefficient (W/m<sup>2</sup>.K)

$k_i$  = thermal conductivity of  $i^{\text{th}}$  layer in the wall (W/m<sup>2</sup>.K)

$x_i$  = thickness of  $i^{\text{th}}$  layer in wall (m)

$E$  = insulation effectiveness factor

$h_i$  = inside convective heat transfer coefficient (W/m<sup>2</sup>.K)

$$h = 7.3 v_a^{0.8} \quad 3.6$$

Where  $v_a$  = air velocity over surface (m/s)

Hourly ambient temperatures were obtained from the ETТА Meteorology Office. All calculations are based on the data for 10<sup>th</sup> April 2001. This simplification is reasonable because past temperature data show that monthly ambient temperature is relatively uniform throughout the year, except for August, which is cooler (Bappeda Propinsi Tingkat I Timor Timur and Kantor Statistik Propinsi Tingkat I Timor Timur, 1997).

The temperature of air-conditioned rooms was set at 22 ° C. This is almost the same as the average minimum temperature in Dili.

Air velocity was set at 0.25 m/s inside the air-conditioned room. This was measured using a Digital Vane Anemometer & Volumetric Flow Hoods type LCA 6000, which provides a direct reading of air velocity.

Air velocity outside was set at 4 m/s (based on the average data for 10<sup>th</sup> April 2001). The ambient air velocity was obtained from the ETТА Meteorology Office in Dili.

## **(2). Ceiling Loads**

Ceiling loads were calculated using equation 3.4.

To account for the hot roof cavity between the roof and the ceiling as a result of solar infiltration, ceiling temperature is assumed to be equivalent to the ambient temperature during the night, but equal to the ambient temperature plus 10 °C from 7AM to 5PM.

## **(3). Floor Load**

Floor load was ignored from the calculation due to the ground floor of all buildings being constructed from concrete and directly sitting on the ground. For upper storeys too, floor load can be ignored because the temperature of those rooms is almost the same as that of the air-conditioned rooms below.

## **(4). Air Interchange Heat Loads**

Air interchange is described as the replacement of cooling air in an air-conditioned room by warm air at ambient temperature (Cleland and Cleland, 1992). Air interchange mainly happens when doors and windows are opened and closed. A good practice of heat load calculation is counting the number of times doors are opened and closed.

However, for the purpose of this study, heat loads of doors and windows were assumed to be zero. One justification for this is that many doors from air-conditioned rooms lead into corridors, which are themselves air-conditioned; this is particularly so in hotels. Windows are normally kept closed at all times.

## **b. People Loads**

The number of people in the room will influence heat loads because people generate heat either in the form of sensible heat or latent heat. According to Cleland and Cleland (1992), a person actively working in an air-conditioned office generates about 500 W. Most of this is generated through heat from breath, rather than heat losses through the skin. When taken across a range of temperature

environments, the average heat load for a person is 350 W. For the purpose of this study, a value of 350 W per person was adopted to calculate people loads, as expressed in equation 3.7.

$$\dot{Q}_{pe} = 350 N_{pe} \quad 3.7$$

Where  $\dot{Q}_{pe}$  = people load and  $N_{pe}$  = number of people in air conditioning area at any time.

People loads were modeled based on the assumption that every room with an area of 24 square meters holds 3 people for all working days and hours. During this time, some workers may go out for external business, but other visitors take their place. People load only affects heat loads during working days and office hours from 8 AM –12 PM and 2 PM – 5 PM. Outside of working hours, it was assumed that all office rooms are vacant; therefore, people load is zero.

For the Regent Hotel (one of the buildings in this sample), the calculation of people loads is different to that for office buildings, largely because each single-bed air-conditioned room in the hotel only holds one visitor. In addition, it was assumed that during working days and working hours, hotel rooms (bedroom) were vacant because many of the guests who were businessmen and government partners seeking government and other private institution services. Therefore, people loads for working hours from 9 AM to 12 PM and 2 PM to 5 PM were neglected.

For the mini market (Hello Mister), the number of people in the room may vary from time to time. The mini market operates from 8 AM to 5 PM seven days a week. The average visitors in the buildings are assumed to be 20 people per hour, although the peak visit time is between 3-5 PM with around 30 people.

### **c. Lighting Loads**

The energy output of a light source is in two forms: light and heat. The total energy output of a light source can be directly read from the wattage of a bulb. The total heat released by the lights is the sum of the wattage of the various

lights operating (Cleland and Cleland, 1992). Lighting load calculation can use equation 3.8.

$$\phi_l = N_l \phi_w \quad 3.8$$

Where  $\phi_l$  = lighting load (W),  $N_l$  = number of light fixtures (W); and  $\phi_w$  = wattage of each light fixtures (W).

Most hotel rooms in East Timor use 1 light fixture of 100 watts. Most office buildings have dimensions of 24 square meters per room, and utilize 2 light fixtures of 100 watts each. As a rule of thumb, we assume that office rooms in East Timor have dimensions of 24 square meters per room, with two light fixtures of 100 watts each per room, although it is acknowledged that some rooms have more than this.

### **3.2. Electricity Demand**

Monthly electricity demand data in East Timor was collected from the ETTA Power Authority. To design cogeneration systems, hourly electricity demand data is required; such data is, however, not available.

Instead, hourly electricity demand was assessed based on three determinant factors, namely air conditioning, lighting and computer, while other factors were ignored. However, in Hello Mister, electricity consumption for driving refrigerators was included in calculation of electricity load.

### **3.3. Heat Source**

Absorption chillers require heat for driving the system. Heat sources for absorption chillers include exhaust gas, steam or hot water, which can be obtained from heat recovery from a cogeneration system or from other process plants. Heat sources (heat inputs) to match heat loads (useful energy) were calculated using equation 3.9.

$$\text{COP} = \frac{\text{Useful Energy}}{\text{Heat inputs}} \quad 3.9$$

Where COP = coefficient of performance of absorption chiller; Useful energy = cooling load produced from absorption chillers; Heat input = heat input to achieve useful energy.

The typical COP of single-stage absorption chillers is 0.6 – 0.7, while for double-stage absorption chillers it is 0.9 – 1.2 (Dorgan *et al.*, 1995). For the purpose of this study, the coefficient of performance of single-stage absorption chiller was set at 0.65 and assumed to be constant. In addition, it was assumed that 65% of heat release would be recovered, from an engine with an efficiency of 30% (Taylor and Labson, 1997 and Onsite Sycom Energy Corporation, 1999).

### **3.4. Fuel availability**

Type of fuels will dictate electricity prices, with high fuel prices leading to higher operating costs resulting in a higher electricity price. Fuel supply also determines the reliability of electricity supply. This is particularly true for a country like East Timor, which is dependent upon importing fuel (diesel) from Indonesia. If fuel supply is too low, the existing prime movers will operate below their capacity, leading to a drop in electricity output. To ensure reliable electricity supply, the cost and continuity of fuel supplies must first be identified. Based on this principle, three potential fuels for East Timor power generation, namely diesel, gas and biomass, are discussed below.

#### **3.4.1. Diesel**

Diesel is the primary energy input for all power generation systems in East Timor. Pertamina, an Indonesian State company, is the sole agency to import and supply diesel for the entire country. Since all diesel is imported, the capacity and the sustainability of diesel supply will depend upon the international market and financial ability of East Timor.

For example, in the year 2000, the East Timor Transitional Administration (ETTA) expected the diesel price to be US\$0.22/liter, while in reality it went up to US\$0.35. This pushed ETTA to provide additional funds of US\$1.7 million to cover the increase in fuel price. An alternative option would have been to introduce new technology with more efficient fuel use, and to invite the participation of the private sector.

### **3.4.2. Natural Gas**

Natural gas could be an alternative fuel to diesel. The benefit of natural gas is it produces lower gas emissions and has the potential to produce high electric capacity. If natural gas is available, it could be used to drive gas turbines for power generation, resulting in the provision of reliable and clean energy.

East Timor has huge deposits of natural gas, both onshore and offshore. The total gas deposit in the Timor Sea is estimated to be around 15.9 trillion cubic feet, with the bulk being in Bayu Undan (3.9 trillion cubic feet) and Greater Sunrise Field (10 trillion cubic feet), and other small fields contributing about 2 trillion cubic feet. Conoco Phillips and its partners will operate the Bayu Undan project over a 25 year period to process 3.9 trillion cubic feet of natural gas. They have spent an initial US\$1.4 million, and if negotiations between the East Timor and Australian governments about sharing revenues of gas production resume soon, Conoco Phillips and its partners will inject more capital to prepare the project to be able to operate in full scale in mid 2007.

If 10 percent of the annual production can be piped to East Timor, it will provide large quantities of clean energy for the country. Unfortunately, Conoco Phillips has no plans to establish a gas pipeline to East Timor, although the Bayu-Undan project is much closer to Suai in East Timor (250 km) than it is to Darwin, Australia (500 km). The reasons are that East Timor has insufficient gas infrastructure (piping and networking) and poor market segmentation, and that the sea on the Timor side of the gas field is deep and contains a volcanic line. It would therefore require huge investment costs for gas networking to East Timor compared to Darwin, Australia.

Petro Timor, a United States company, has however offered a proposal to establish a gas pipeline to East Timor. This proposal seems an attractive option for East Timor, not only because it will provide much gas to substitute for diesel, but also because it would provide many job opportunities.

If the East Timorese government moves quickly by providing adequate security and infrastructure, there could be some investors interested in producing gas onshore. However, such proposals could only be possible after the next 5 years, because it would take time to build infrastructure and prospect for gas reserves.

### **3.4.3. Biomass**

Biomass energy could become an alternative technology to substitute for diesel in some areas in East Timor. Biomass in the form of rice husks and coconut shells is largely produced in districts such as Viqueque, Lautem, Baucau, Manatuto, Maliana and Suai. It is estimated that the annual production of rice husk is 150 tonnes/year and coconut shells is 120 tonnes/year, giving a total biomass from both types of about 270 tonnes/year. Based on the United Nations Economic and Social Commission for Asia and the Pacific's (2000) assumption that 2.7 kg of husk are necessary to produce 1 KWh of electricity, then the annual electricity production from this combined biomass would be 62,962.96 KWh (62.96 MWh) or 5.3 MWh per month.

However, this biomass does not have the potential to be used as fuel because it comes from geographically dispersed districts, resulting in unviable transport costs. Even if there were enough biomass available in the one district, lack of skilled people to operate and maintain steam turbines based on biomass fuel also discourages the adoption of biomass steam turbine cogeneration systems.

## **3.5. Cogeneration Option**

Chapter 4 presents the author's choice of cogeneration system, based on site energy demand, fuel, and space availability. The cooling from the cogeneration plant was designed to operate only during working hours, from 8 AM to 5 PM Monday to Friday, since the main consumers of cooling are from

nearby business and government buildings. Outside of these hours, any cooling requirements would be met by an electric cooling system. Because office-hour cooling requirements are met by the cogeneration plant, electricity demand is reduced, allowing excess capacity to be exported to the local grid.

Cogeneration could not be used to produce ice for food preservation due to its high operational cost and poor refrigeration load in East Timor. For example, the Hello Mister Supermarket, the largest supermarket in Dili, only employs 8 refrigerators. In such a situation, ice and cooling production for food preservation is better obtained from an electric refrigeration system, while cogeneration provides cooling for buildings.

## **CHAPTER 4 SIZING COGENERATION**

### **4.1. Energy Demand**

#### **4.1.1. Electricity Load**

Most buildings obtain electricity from Eletricidade de Timor Leste (EDTL). Electricity is mainly consumed for lighting and driving equipment such as computers, air conditioning, and refrigerators. Most buildings have electricity installations below 100 kilowatts, except the United Nations Transitional Authority for East Timor (UNTAET) Building, which uses 200 kilowatts. In fact, many buildings have electricity installation capacities of below 25 kilowatts. In these buildings, electricity is primarily used for lighting and computers. Many buildings have electricity installation capacity below 25 kilowatts; these do not have air-conditioning.

For instance, the Central Payment Office (CPO) building is smaller than the Sumaflow, the biggest shop in East Timor, but the CPO's electric installation capacity is 50 kilowatts while the Sumaflow only 24 kilowatts. The higher electric installation capacity in Central Payment Office building is due to air conditioning, which Sumaflow does not have.

Cogeneration systems are only viable if a site requires both electricity and thermal energy. Most buildings in Dili are unsuitable as cogeneration sites, since their electricity and thermal demands are too low. Based on this principle, a set of six buildings in Dili was selected as a potential cogeneration site. These buildings are the UNTAET, the National University of East Timor (UNATIL), the mini-market Hello Mister, the Regent Hotel, the Central Payment Office (CPO) and the bank Banco Nacional Ultramarino (BNU). These buildings are selected not only based on their proximity to one another but also on their relatively high electric and cooling demands.

Table 4.1 shows that the total electricity installation capacity in these selected buildings is 505 kilowatts. However, in practice, electric consumption is lower than the installation capacity. This is particularly the case since the

electricity is predominantly used for driving air conditioning, for which the load varies according to ambient temperature change, people load and lighting load. In addition, during certain periods, some equipment and lighting are turned off.

Table 4.1. Electric Installation Capacity of Selected Buildings

NAME OF BUILDING	INSTALLATION CAPACITY (KW)
Regent Hotel	70
UNATIL	60
Hello Mister	50
UNTAET	200
CPO	50
BNU	75
Total	505

Source: Eletricidade de Timor Leste (2001)

To obtain a more accurate picture of electricity demand, hourly electricity consumption was modeled based on air conditioning, computers, lighting and refrigerators, while other potential electricity applications were ignored. Assuming that the coefficient of performance (COP) of electric air conditioning is constant at 2.2 (Mitsubishi Electric Comfortmaster, 2001), then hourly electric consumption for cooling systems can be calculated using equation 3.9. The result of this equation was summed with electric consumption for computers, lighting and refrigerator, and the totals are shown in Figure 4.1.

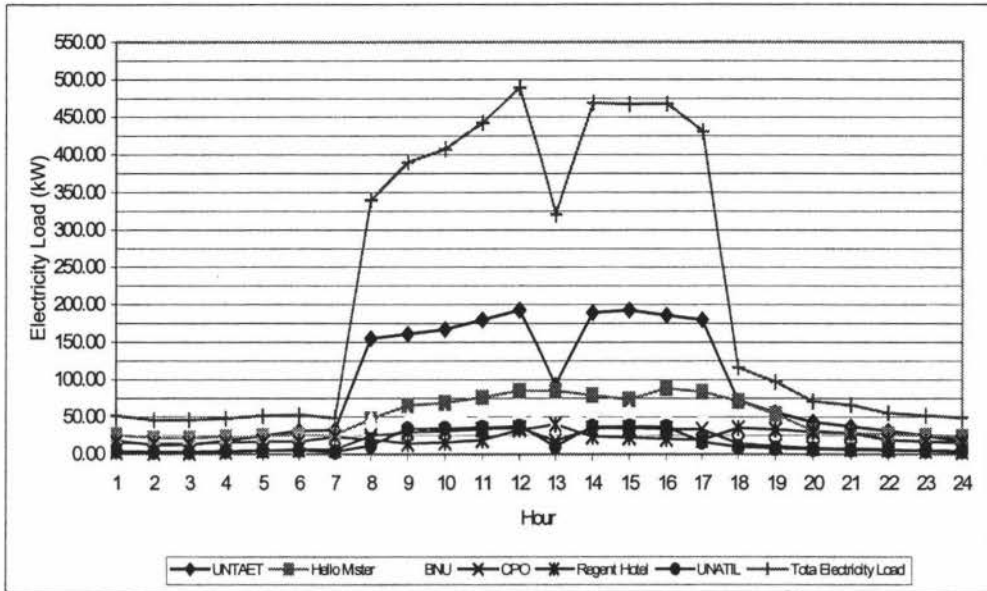


Figure 4.1. Hourly Electricity Load in Selected Buildings

Figure 4.1 thus shows the typical daily electric demand of the selected buildings. Cooling systems are the main driver of electricity load, with computers and lighting also having an effect. As most of the buildings are offices, electricity loads in these buildings are predominantly high in working hours, while post-working hours, there is a sharp drop of electricity load due to air conditioning, computers and lights being turned off.

At 8 AM, electricity loads increase markedly because air conditioning, computers and lights are activated in the offices. From 8 AM to 12 noon the electricity loads continue to rise, due to a rise in the ambient temperature and people and lighting loads. However, from 12 noon to 2 PM, electricity loads decrease because of the decrease in the number of people occupying the building and lighting loads. In this period, buildings are assumed vacant due to all personnel is going to take lunch while lights are turned off. After 2 PM, electricity load is increased due to all personnel being in place and lights being switched on, resulting in an increased electricity consumption for driving cooling systems due to temperature change, people and lighting load. However, at 4 PM, electricity load is slightly decreased because of lower electricity consumption for driving air conditioning due to the drop in ambient temperature. After working hours (5 PM),

there is a plunge in electricity loads due to all cooling systems and lights in the buildings being deactivated, the exceptions being the Regent Hotel and Hello Mister Mini Market.

#### **4.1.2. Cooling Demand**

Within the six buildings selected to assess cooling demand, the total number of air conditioners is 285 units, with an overall installed cooling capacity of 698 kilowatt. The electric cooling capacity was calculated based on the type of the existing air conditioning and specifications from manufacturers. Most of the existing air conditioners are window types manufactured by Mitsubishi with a cooling output of 2.45 kilowatt-cooling and a coefficient of performance of 2.2.

In practice, cooling consumption of an air conditioning system does not consistently reach the installation capacity because heat removal is also dependent upon construction of the buildings, number of occupants, lighting and ambient temperature. To determine hourly cooling consumption in selected buildings, the heat load of each building should first be modeled. This will provide the precise data of cooling consumption required to design a cogeneration system.

The heat loads were modeled using a room-by-room approach. It accounted for factors such as surface infiltration heat and internal heat gain. Surface infiltration heat loads include heat transmission through wall and roof, while air interchange loads comprise people and lighting loads. Windows and doors were not counted in heat load calculations due to windows being closed at all times, while doors are only occasionally opened. In addition, doors in air-conditioned rooms open to a corridor inside the building, where the temperature is almost the same as the room temperature. However, doors and windows were accounted for in the calculation as part of the wall, because of their different thickness and conductivity. Floor load was ignored due to the foundation of the buildings being closely joined to the ground and constructed from concrete, so that heat infiltration from the ground is assumed to be zero. The temperature of floors of upstairs rooms was assumed to be the same as the temperature downstairs because both floors have installed air conditioning.

Based on the above considerations, the calculated hourly heat loads of the selected buildings are presented in Figure 4.2.

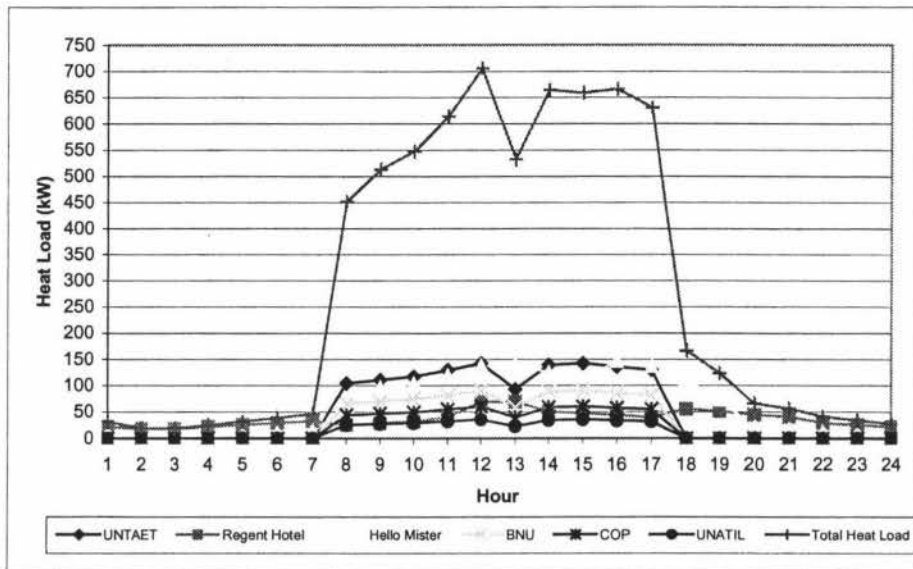


Figure 4.2. Hourly heat loads of selected buildings

The peak load occurred on working days at midday with a total heat load of 707 KW, while the minimum load of 49 KW occurred from 2 AM – 3 AM. The peak load was primarily driven by three factors: ambient temperature, people load and lighting. From 8 AM until midday, the dramatic growth of ambient temperature caused heat loads of the buildings to sharply increase. From midday to 2 PM the heat load slightly dropped despite the increasing temperature, because of no personnel and lighting in the air-conditioned rooms, as personnel go out for lunch and lights are turned off.

The drop in heat loads in office buildings during lunchtime could be compensated by the increase in heat loads of Hello Mister and the Regent Hotel. This is because during lunchtime, people numbers in both buildings increase due to the presence of visitors and the rise in ambient temperature. For example, it was assumed that during lunchtime, all visitors in the Regent Hotel are back in place for lunch and rest, while government and commercial offices are closed. This increases heat loads in two ways: personnel loads and light loads due to light utilisation in the air-conditioned rooms. In Hello Mister, the increase in heat load was driven by two factors: Increasing ambient temperature and increased people load, due to government officers dropping in during their lunch hour.

The heat loads on weekends was extremely low, as compared to the heat loads during working days (Figure 4.3). This was because during weekends all government and business offices were closed. Therefore, the total heat load was driven only by the heat loads of the Regent Hotel and Hello Mister.

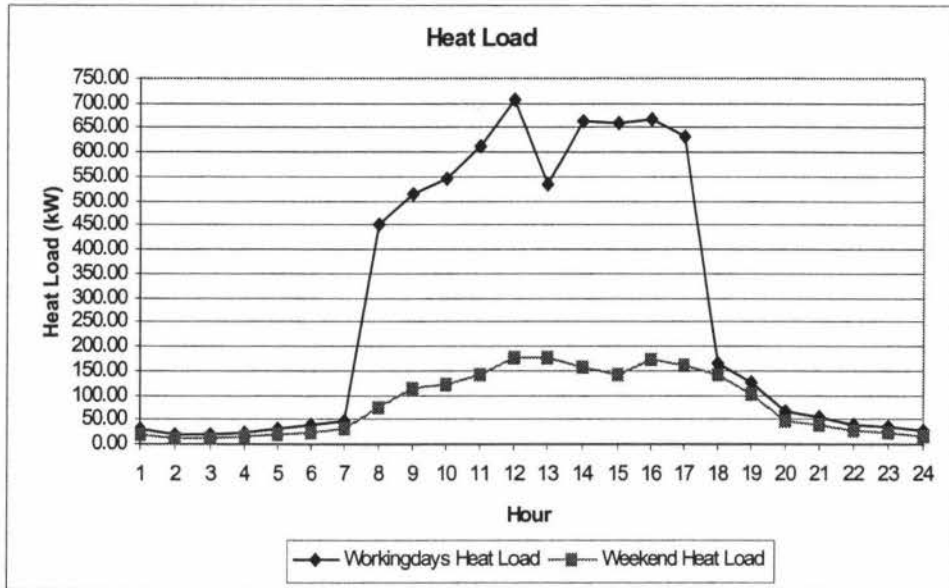


Figure 4.3 Comparison of total heat load during weekdays and weekends

In temperate countries, the temperature and humidity vary greatly across the 4 seasons. In summer, the temperature is high while in winter temperature is low. In such situations, profiles of seasonal temperature and humidity are necessary to model seasonal heat loads. In East Timor the case is different. Dili only has two seasons: Dry and wet season, where the average temperatures of both seasons are almost the same. In the wet season, the average minimum temperature 21 °C and maximum is 32 °C, while in the dry season, the average temperature range (even taking into account the slightly cooler nights of August) is 22 °C to 34 °C. If the number of people and light fixtures in air-conditioned rooms is assumed constant, the heat loads for the two seasons are quite similar. Good practice for heat load calculations also account for humidity change between the two seasons. Unfortunately, hourly humidity profiles are not available in East Timor.

## 4.2. Cogeneration Option

The type and size of cogeneration systems depends on electricity demand and fuel availability. Table 4.2 summarizes total hourly electricity and cooling demand for the selected buildings.

Table 4.2. Total Electricity and Cooling Demand between 8 AM and 5 PM for the 6 Selected Buildings

<b>TYPE OF DEMAND</b>	<b>UNIT</b>	<b>ENERGY DEMAND</b>
Max Elect Consumption	KWe	489
Minimum Elect Consumption	KWe	340
Average Elect Consumption	KWe	422
Max Cooling Consumption	KW	707
Min Cooling Consumption	KW	452
Average Cooling Consumption	KW	600

The average electricity load is 422 kilowatts-electricity, of which 273 kilowatts are used to drive air conditioning. Thus, if the electric cooling system were to be replaced by an absorption cooling system, average electricity consumption would drop to 149 kilowatts. This electricity capacity is too small to design a cogeneration system because the heat output of an engine with 149 kilowatt-electricity will not be adequate to drive an absorption chiller in order to produce cooling capacity of 600 kilowatts.

To overcome the small electric capacity and to meet cooling demand, a cogeneration system was designed not only to meet the electricity demand of the selected buildings but also to export electricity to the grid. Exporting electricity is possible due to Dili currently facing a deficit of electricity supply. If the cogeneration system is designed to meet the average cooling requirement of 600 kilowatts, then during peak cooling load, some of the electricity produced will be used to drive an electric cooling system to supplement the absorption chiller. This will of course reduce revenue gained from exporting electricity.

If the average cooling capacity is 600 kilowatts, then, in order to release enough heat to drive the absorption chiller, the engine size should be 608 kilowatts of electricity. This engine size is based on the assumption that the engine efficiency is 30 percent, recoverable heat is 65 percent, and coefficient of performance of a lithium bromide-water single-effect absorption is 0.65.

If electricity demand of a site is less than 1 megawatt, a reciprocating engine is most suitable. The advantages of reciprocating engines are high electricity output and diesel availability. In addition, diesel engine technology is well-known in East Timor; it should therefore be easily operated and maintained. However, the disadvantages of the engine include high CO<sub>2</sub> emissions and high noise levels. Nevertheless, CO<sub>2</sub> emission has not become a priority in East Timor due to the lack of alternative technology to replace diesel engines. In a small country like East Timor, the priority factors are that the chosen energy technology offers a reliable electricity supply, is cheap, and is easy to operate and maintain.

To export extra electricity, the cogeneration system has to be designed to operate for at least 5376 operating hours annually, that is, 16 hours per day, from 8 AM to 12 midnight. After this period, the cogeneration system is shut down. This is aimed to avoid any losses occurring due to the cogeneration plant being operated under its designed capacity. In principle, one could design a cogeneration system to operate in full scale throughout the year, but this would leave large amounts of fuel input unconverted and released as "Waste heat". If this occurred, the aim of the cogeneration plant to increase efficiency of fuel use would be jeopardised.

The absorption cooling machine is designed to fit the cooling demand of the selected buildings during working hours. Therefore, its operational hours are 9 hours per day from Monday to Friday, totalling 2160 hours annually. It would not be wise to produce cooling outside of this operational time because it would increase operating costs while cooling consumption was low. Therefore, outside of these operational hours, buildings such as the Regent Hotel and Hello Mister Mini Market could substitute their cooling system with electric air conditioning. This is particularly true because the cooling load of both buildings is low.

## **CHAPTER 5**

### **ECONOMIC ANALYSIS**

This chapter aims to assess the financial viability of the cogeneration system designed in the previous chapter. All costs such as capital, operating and maintenance costs were based on 2001 figures, and calculated based on the current electricity and cooling demand. Therefore, any electricity growth in the future was ignored.

To carry out detailed financial analysis, all relevant costs have to be accurately identified. Many of the costs were available in the literature; however, the rule of thumb had to be applied at times.

#### **5.1. Investment Costs**

The total investment costs of a cogeneration plant comprise costs of the engine package, absorption cooling unit, land, buildings, pipe and networking and cooling coils. These will be considered in turn, and summarised in Table 5.1 below.

Figure 5.1 shows the investment costs (US\$ per kilowatt-electricity) for various sizes of reciprocating engine cogeneration systems (excluding the absorption chiller units) in East Timor. This figure was derived by interpolating the data of Onsite Sycom Energy Corporation (2000) using Microsoft Excel software. Since East Timor has no experience with cogeneration, all non-equipment costs were assumed to be the same as those in the United States. Equipment costs in East Timor take into account the 25% cost insurance freight (CIF) and 10% import tax imposed by the East Timor Transitional Administration's tax regulation.

Figure 5.1 shows that, for capacities below 1000 kilowatt-electricity, the capital costs per kilowatt-electricity decrease with increasing engine capacity. For capacities above 1000 kilowatt-electricity, investment costs stay fairly constant. Unfortunately, the cost-effectiveness of larger engines cannot be taken advantage of in the selected buildings, because both average electricity and cooling capacity of these buildings are below 1000 kilowatts. If a large engine were selected, it

would allow much primary energy input to remain unconverted and be released as “Waste heat”, thus decreasing the cost savings offered by the cogeneration system.

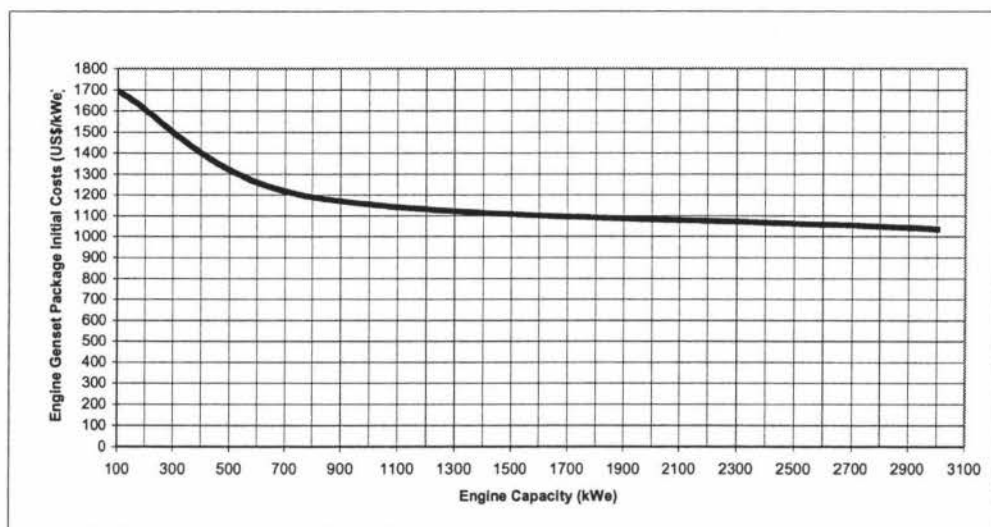


Figure 5.1. Investment costs of reciprocating engine cogeneration system in East Timor (excluding Absorption chiller unit) relative to engine capacity. Derived from data of Onsite Sycom Energy Corporation (2000).

Initial costs of single-effect lithium bromide-water absorption cooling systems were calculated using data from Dorgan *et al.* (1995). Dorgan *et al.* (1995) quote the capital cost of a single-effect lithium bromide-water absorption chiller machine with a nominal size of 900 kilowatt as US\$95-US\$190 per kilowatt. Therefore, capital costs of US\$152 per kilowatt for a machine with a nominal size of 600 kilowatt seem reasonable. The above costs are in 1994 and 1997 figures; it thus has to be converted into a 2001 price by using the chemical plant cost index of 365.7 for heat exchangers, as published in Chemical Engineering Magazine April 2001.

The total land area for the cogeneration plant was assumed to be 1000 square meters. Land price and building construction per square meter are US\$5 and US\$50 respectively. Installation and housing of the cogeneration system are included in the engine package costs above. Networking and piping were assumed

to be 2.5 percent of the total package costs (United Nations Economic and Social Commission for Asia and the Pacific, 2000).

Table 5.1. Total Investment Costs of a 608 KW<sub>e</sub> Reciprocating Engine Cogeneration Plant in Dili (US\$)

<b>ENGINE UNIT</b>	<b>Capacity of Engine (KWe)</b>	1	608
	<b>Installation Cost Per Kilowatt</b> (includes heat recovery cost)	2	1250
	<b>Total Installation Costs</b>	3 (1x2)	760000
<b>ABSORPTION CHILLER UNIT</b>	<b>Abs. Chiller Machine Cost</b> (nominal size equal to 600kWt)	4	106691
	<b>Heat Rejection Cost</b>	5	55269
	<b>Cooling Coil Cost</b>	6	21375
	<b>Total Abs Chiller Unit Cost</b>	7 (4+5+6)	183335
<b>Total Package Costs (engine + Abs. Unit)</b>		8 (3+7)	943335
<b>Pipe and Network (2.5% of total cost)</b>		9	23583
<b>Purchase Land for Site (1000 m<sup>2</sup> at US\$5/m<sup>2</sup>)</b>		10	5000
<b>Construction of Buildings (200 m<sup>2</sup> at US\$50/m<sup>2</sup>)</b>		11	10000
<b>Total Investment Costs</b>		12 (8+9+10+11)	<b>981918</b>

The engine and absorption cooling system costs are the main parameters driving the total investment cost. These are in turn dependent on the size of the engine and of the absorption cooling machine. The larger the engine size, the higher the total investment cost, although it is much cheaper on the basis of dollar per kilowatt. There will therefore be a significant reduction of investment cost if the cogeneration system can use smaller engine. This is not an option in this case because the smaller engine size would not generate adequate electricity and cooling to meet end user demand. For example, if the engine capacity were reduced to 400 kilowatt, would result in a lower total investment cost for the cogeneration system. However a 400 kilowatt engine will not be adequate to produce heat required for driving an absorption chiller with cooling capacity of 600 kilowatt-cooling.

The investment costs of a conventional system comprise only air conditioning equipment and installation. The 2001 price per unit of air conditioning in East Timor is US\$400 for Mitsubishi MW-09MV (window type) with a cooling capacity of 2.45 KW cooling. Installation costs were US\$5 per unit

air conditioning, based on low labour costs as advised by sellers in East Timor. The resultant investment cost of a conventional system is shown in Table 5.2.

Table 5.2. Investment Cost of Conventional Air Conditioning System

<b>Cost Per Air Conditioner Unit (US\$)</b> (including installation costs)	405
<b>Number of Air Conditioners in the Selected Buildings</b>	285
<b>Total Costs (US\$)</b>	115425

## 5.2. Operating Costs

The operating costs of a cogeneration system consist of energy and maintenance costs. This should be less than the operating costs for conventional power generation because a cogeneration system consumes less fuel to produce the same amount of energy, leading to savings of energy and operating costs. However, energy savings in a cogeneration system depend on fuel and electricity prices. If the prices of fuel and electricity are low, then operating costs are also low. However, a lower electricity price will also reduce revenues generated from the cogeneration system. Ideally, to reduce operating costs and increase revenues from a cogeneration system, the price of fuel should be as low as possible and the electricity price as high as possible. Unfortunately, this ideal is not met in East Timor, where the fuel price is comparatively higher than the electricity price.

Another element of operating costs is labour. In general, lower wages will result in reduced operating costs. However, lower labour wages could also mean less-skilled people. In this case, if trouble occurs, cogeneration operation could be delayed due to unskilled people not being able to provide trouble-free service. This could decrease electricity and cooling supply, reducing annual cogeneration revenues and creating dissatisfaction amongst users.

In East Timor, the 2001 fuel price fluctuated between US\$0.25-0.35 per liter. In an open market, such a high fuel price would result in a high electricity price. However, in reality, the electricity price in East Timor has been constantly set at US\$ 0.123 per kilowatt-hour. Therefore, when the fuel price increases, the subsidy required in order to maintain flat electricity prices also increases.

As shown in Table 5.3, the total annual operating cost for the cogeneration system is US\$935,806, while the operating cost for the existing electric and cooling system is US\$110,608.

Table 5.3. Operating Costs of 608 Kilowatt Cogeneration Plant in Dili

ENGINE CAPACITY (KWe) (Engine efficiency 30%)		1	608
FUEL CONSUMPTION (KW)		2	2027
OPERATING HOURS PER YEAR (HOURS)		3	5376
ANNUAL FUEL CONSUMPTION (KWh)		4 (2x3)	10895360
ANNUAL FUEL CONSUM (Liter)		5 (4x0.26)	2832794
FUEL PRICE PER LITER (US\$)		6	0.325
ANNUAL FUEL COSTS (US\$)		7 (5x6)	920658
ABSORPTION COOLING UNIT	ANNUAL OPERATING COST OF ABS. MACHINE COSTS (US\$)	8	1435
	ANNUAL OPERATING COST OF COOLING TOWER (US\$)	9	1331
	ANNUAL OPERATING COST OF PUMP (US\$)	10	2734
	TOTAL ELECT. COST (US\$/Year)	11 (8+9+10)	5500
ANNUAL WAGES (US\$)		12	9648
<b>TOTAL ANNUAL OPER. COSTS (US\$)</b>		<b>13 (7+11+12)</b>	<b>935,806</b>

Notes:

2. Liter per kilowatt-hour: 0.26 (T. Fry, pers. comm. 2001 and Weston, 2001)

8, 9 and 10. Chiller's annual operating hours = 2160 hours; chiller, pump and cooling tower's electrical use (See Dorgan *et al*, 1995), Electricity price=US\$0.123 per kilowatt hour

12. Level 5 monthly wages for four 4 people @ US\$201 per person (UNTAET, 2001)

### 5.3. Revenue

The size of the cogeneration system was set so as to meet the heat load and electricity demand of the selected buildings, with the extra power generated being exported to the grid utilities. This cogeneration system can thus generate revenue from two main sources: electricity saving (as a result of not needing to buy so much electricity for cooling) and electricity export to the local grid.

Cogeneration system owners pay for electricity from the local grid at the standard price; however if they sell excess electricity to the local utility grid, they receive a lower price. This is understandable as the local utility pays the overheads of electricity networking. However, in this case study, it was assumed that electricity prices for both electricity saving and electricity export are the same at US\$0.123 per kilowatt-hour. This assumption was based on the fact that East Timor faces a deficit of electricity supply while the government has insufficient financial means to build new power station. Therefore a higher electricity

exporting price should be considered as an investment incentive to encourage the private sector to become involved in supplying electricity. Since four of the buildings in the cogeneration system designed above are owned by the government, there should be no administrative obstacles to exporting electricity to the grid for the same price as that paid by consumers.

As with operating costs, the revenue from a cogeneration system is dependent upon the electricity price. A higher electricity price will result in higher revenue from the cogeneration system. Based on the current fuel price of US\$0.325 per liter and electricity price of US\$0.123 per kilowatt-hour, the revenue from the cogeneration system is shown in Table 5.4.

Table 5.4. Revenue Generation from Cogeneration System

Engine Cap.	1	608
Annual Operating Hours (Hours)	2	5376
Annual Elec Generation (KWh)	3 (1x2)	3268608
Annual Elect Consum (KWh)	4	801024
Cost electricity per kilowatt-hour (US\$)	5	0.123
Cost of Annual Elect. Consum (US\$)	6	98526
Annual Elect Export (kWh)	7 (5x6)	2467584
Cost Elect. Export per kilowatt-hour (US\$)	8 (2-5)	0.123
Annual Elect. Export Price (US\$)	9 (6x8)	303513
Total Annual Revenue (US\$)	10 (7+9)	<b>402039</b>

## 5.4. Assessment of Financial Viability

### 5.4.1. Net Present Value (NPV)

Net present value (NPV) is one of the key parameters in assessing the financial viability of a project. If the net present value of a project is higher than zero, then financially this project can be accepted. A higher net present value indicates that the project can generate adequate revenue to cover both capital and operating costs. If two projects are compared, the one with the highest net present value is the most viable financially.

This study used the above principle to test the financial viability of the cogeneration system. The net present value can be calculated using equation 5.1. However, the net present value for this case study was calculated using Financial Function in Microsoft Excel Software, based on costs and benefits. Using a

discount rate of 10 percent and a project life of 15 years, the net present value of both cogeneration and conventional system is shown in Table 5.5.

$$NPV = \sum_{t=0}^n \frac{(B_t - C_t)}{(1 + r)^t} \quad 5.1$$

Where NPV refers net present value, C refers costs incurred in any future year, B refers to the benefit received in any future year, t refers to time and r donates for discount rate.

Table 5.5. Net present value (NPV) of cogeneration and conventional system

YEAR	COGENERATION SYSTEM					CONVENTIONAL SYSTEM					
	Initial Cost (US\$)	Annual Operating Costs (US\$)	Annual Maintenance Costs (US\$)	Annual Revenue (US\$)	Annual Net Revenue (US\$)	Initial Costs	Annual Replacement Costs (US\$)	Annual Operating Costs (US\$)	Annual Revenue (US\$)	Annual Net Revenue	
1	2	3	4	5	6	7	8	9	10	11	
0	981918	0	0	0	-981918	115425	15390	0	0	-130815	
1	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
2	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
3	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
4	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
5	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
6	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
7	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
8	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
9	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
10	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
11	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
12	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
13	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
14	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
15	0.00	935806	42492	402039	-576259	0.0	15390	82533	0	-97923	
<b>NPV (discount rate =10%)</b>					<b>-5364991</b>	<b>NPV (discount rate = 10%)</b>					<b>-875629</b>

The net present value of both power systems is lower than zero, indicating that neither system is viable financially. The net present value of the cogeneration system is -5,364,991 whereas that of the conventional system is -875,629. This

means both projects cannot generate sufficient revenue to cover both investment and operating costs. However, the conventional system is the best option due to its higher net present value. Both systems will also never achieve the pay-back period due to revenues generated being inadequate to recover initial and operating costs.

The lower net present value of cogeneration is caused by high investment and operating costs. Although a cogeneration system could generate revenues from saving and exporting electricity, this revenue cannot cover investment and operating costs, because the electricity price is lower than the fuel price, primarily as a result of a high electricity subsidy. In fact, during the financial year 2000/2001, the electricity subsidy amounted to US\$818,000.

Currently, the fuel price is US\$0.325 per liter, while the liter per kilowatt-hour ratio is 0.26. Under these conditions, a cogeneration system will only become an attractive option if the electricity price can be set at US\$0.35 per kilowatt-hour. With this price, a cogeneration system would generate enough revenue to recover both capital and operating costs. In addition, the higher electricity price would also lead to increasing the operating cost of a conventional system, resulting in a lower net present value (see Figure 5.2).

#### **5.4.2. Internal Rate of Return (IRR)**

Internal rate of return (IRR) is defined as a sequence of cash flows is the rate that makes the Net Present Value (NPV) exactly zero, in that it equates the present value of the cash inflows and outflows. This can be expressed using equation 5.2.

$$\text{IRR} = \sum_{t=0}^n \frac{(B_t - C_t)}{(1 + r)^t} = 0 \quad 5.2$$

Where IRR refers internal rate of return, C refers costs incurred in any future year, B refers to the benefit received in any future year, t refers to time and r donates for discount rate.

The common rule for IRR is that if the IRR of a project is lower than the minimum rate of return for investment (MARR), then the project should be rejected. If it is higher, then, depending on the NPV, the project could be acceptable.

The common rule for IRR is that if the IRR of a project is lower than the minimum rate of return for investment (MARR), then the project should be rejected. If the IRR of a project is above the MARR, then, depending on the NPV, the project may be acceptable. If two projects are considered, and both projects have a positive IRR, both the IRR and the NPV of the project should be considered (Perkins, 1994: 74, and Department of Finance, 1994: 51). The IRR of the cogeneration option for this study was not calculated because the NPV of the cogeneration system is below zero. This means that both cogeneration and conventional cooling systems will not generate adequate revenue to cover investment and operation costs during their operation period.

#### 5.4.3. Sensitivity Analysis

Sensitivity analysis aims to assess the change in net present value in response to changes in the key parameters. According to Perkins (1994:359), a sensitivity analysis of a project simply entails varying key parameter values, singularly or in combination, to determine the impact of such manipulations on the project's net present values.

For the purpose of this study, two key parameters, namely as fuel and electricity prices, were varied to assess the sensitivity of the cogeneration system.

Table 5.6. Sensitivity analysis of net present value (NPV) of cogeneration system at various fuel and electricity prices using a discount rate of 10 percent.

FUEL PRICE PER LITER (US\$)	NPV (Discount rate=10%)						
	Elec Price Per KWh= US\$ 0.123	Elec Price Per KWh= US\$0.20	Elec Price Per KWh= US\$0.25	Elec Price Per kWh= US\$0.275	Elec Price Per KWh= US\$0.30	Elec Price Per KWh= US\$0.325	Elec Price Per KWh= US\$0.35
0.20	-2659254	-771123	454936	1067966	1680995	2294025	2907054
0.225	-3197915	-1309784	-83725	529304	1142334	1755363	2368393
0.25	-3736576	-1848445	-622386	-9357	603673	1216702	1829732
0.275	-4275238	-2387107	-1161048	-548018	65011	678041	1291070
0.30	-4813899	-2925768	-1699709	-1086680	-473650	139379	752409
0.325	-5364991	-3464430	-2238370	-1625341	-1012311	-399282	213748
0.35	-5891222	-4003091	-2777032	-2164002	-1550973	-937943	-324914
0.375	-6429883	-4541752	-3315693	-2702664	-2089634	-1476605	-863575
0.40	-6968544	-5080414	-3854354	-3241325	-2628295	-2015266	-1402236

Table 5.6 shows that the NPV of the cogeneration system depends upon fuel and electricity price. If the fuel price is lower and the electricity price is higher, the cogeneration system becomes an attractive option compared to a conventional system. For example, if the fuel price is US\$0.20 per liter and the electricity price is US\$0.25 per kilowatt-electricity, then the NPV will be US\$907,818. The highest NPV will be achieved with the lowest fuel price and the highest electricity price. This is mainly due to the increase of revenues generated from both displaced and exported electricity.

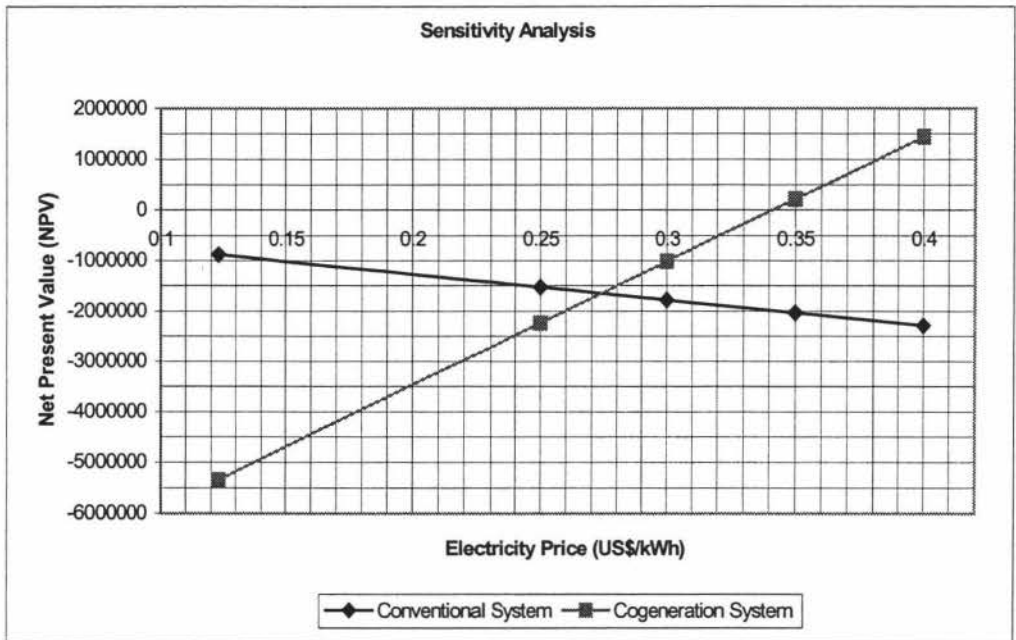


Figure 5.2. Net present value of cogeneration and conventional system at various electricity prices (Fuel price=US\$0.325 per liter).

## **CHAPTER 6**

### **CONCLUSIONS AND RECOMMENDATIONS**

#### **6.1. Conclusions**

Cogeneration systems represent a well-established technology, which generates heat and power simultaneously using a single primary energy input. Cogeneration will recover “waste heat” from a conventional power generation to produce useful energy leading to an increase in the overall efficiency of fuel input. This also achieves a cost saving and reduces greenhouse gas emissions.

As a new country, East Timor requires an adequate electricity supply to support economic growth. However there is clear evidence that East Timor faces an electricity deficit of 24 megawatts, which is even greater than the current operable electric capacity of 22 megawatts. Electricity demand is predominantly driven by residential consumption while commercial and industrial consumption is low.

Electricity consumption in all buildings is below 100 kilowatt-electricity, with the exception of the United Nations Transitional Administration for East Timor (UNTAET) building. The electricity demand in most buildings is lower because electricity is mainly used for lighting. In higher electricity installation buildings, electricity consumption is primarily driven by computer and air conditioning systems.

The cooling demand for food and buildings is low because most people live in poverty in which cooling is not a consideration. In addition, demand is not concentrated in one geographical area.

Due to electricity and cooling loads being below 700 kilowatts, a reciprocating cogeneration system is the best option. In addition, East Timor already has people who are experienced in maintaining and operating diesel engines. The size of the cogeneration system was set to meet the site’s electric demand and also export to the local grid. Exporting electricity will contribute to reducing the electricity deficit and also provide revenue for the cogeneration plant.

However, the financial analysis reveals that both cogeneration systems and conventional systems are not viable options because the NPV of both systems are below zero. In fact, the NPV of the cogeneration system and of the conventional system are -5,364,991 and -875,629 respectively. The negative NPV mean that both systems cannot generate sufficient revenue to cover capital and operating costs, and thus cannot achieve pay-back during their lifetime. However, the conventional system is much better than the cogeneration system.

Based on sensitivity analysis, a cogeneration system is very dependent upon electricity and fuel price. A lower fuel price and higher electricity price would increase cogeneration viability. However, increasing the electricity price would require removing the current subsidy. This would not be acceptable as a large majority of the people can hardly afford electricity, and raising the price would increase the gap between 'haves' and 'have-nots'. Increasing the electricity price would also discourage investors' from investing in East Timor.

## **6.2. Recommendations**

1. The East Timorese government should provide adequate electricity to support economic growth. Poor electricity supply will decrease the comparative advantage of East Timor for investment compared to other neighbouring countries such as Indonesia and Australia.
2. To increase power supply, the private sector should be involved in power generation, since the government has insufficient revenue to do so. Therefore, the East Timor government should provide clear policy frameworks and tax incentives to encourage private investment.
3. The East Timorese government should negotiate with Conoco Phillips to construct a pipeline to pipe some of the gas from the Timor Gap to East Timor in order to replace the expensive diesel from Indonesia. This should lead to financial savings and provide clean energy.

4. Cogeneration systems are attractive in that they can provide reliable electricity and clean energy. However, based on financial analysis, a cogeneration system is not a viable option for East Timor. Therefore, it should not be adopted as a substitute for the existing electric generation system.

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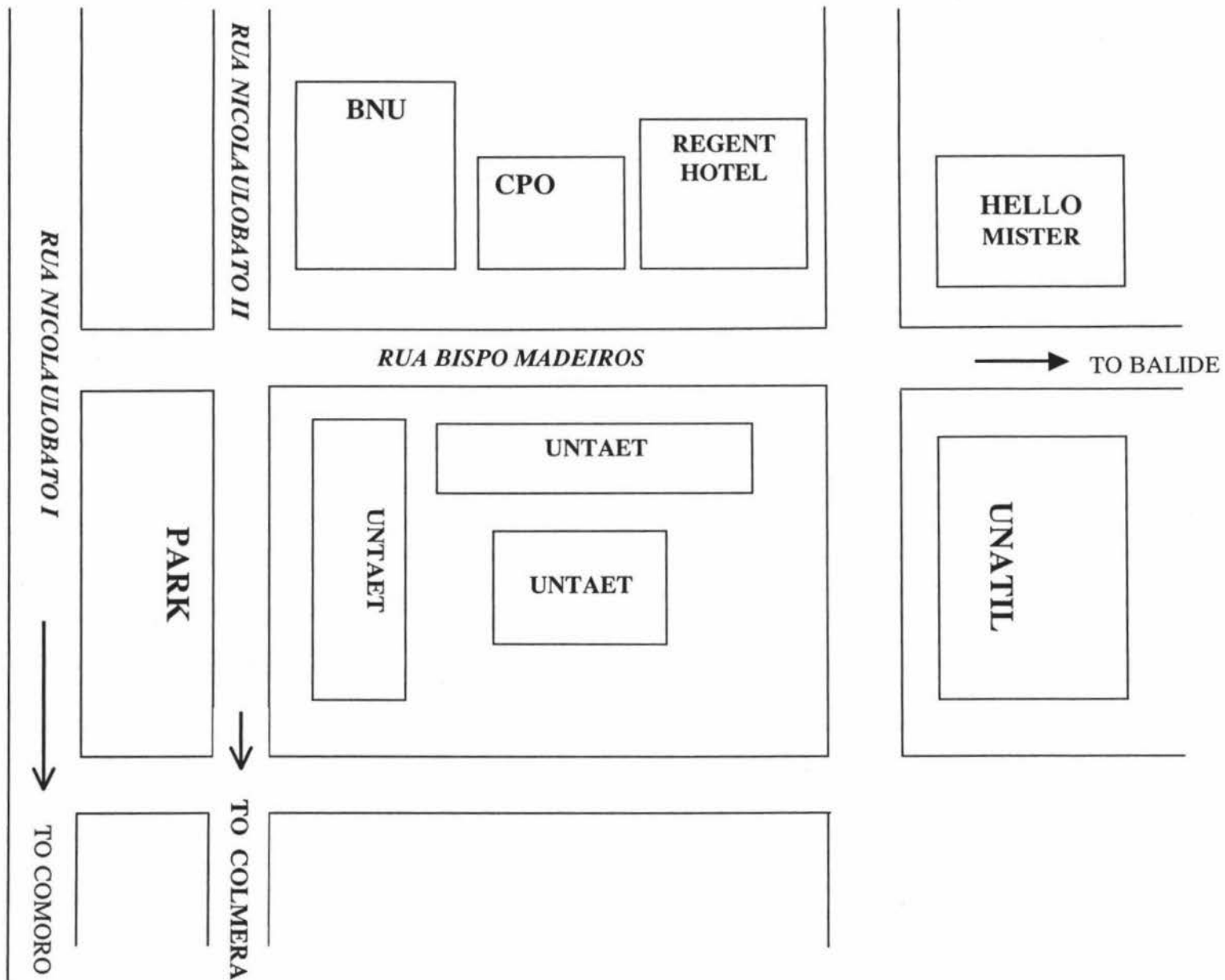
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## **APPENDIX**

APPENDIX A. FIGURE OF CONGENERATION SITE IN DILI, EAST TIMOR



**Appendix B1. Heat and Electricity Load of UNTAET Building**

	Unit	Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<b>1. Surface Infiltration Heat Load</b>																									
Ambient Temperature (T amb.)	oC	23	22	22	23	24	25	26	27	28	29	31	33	33	34	33	32	31	30	29	27	26	25	24	23
Inside Room Temperature (T Room)	oC	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
<b>1.1. Ceiling Load</b>																									
1.1.1. Ceiling Surface Area (A)	m2	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	
1.1.2. Coefficient of conductivity (ki) for Plywood	W/m.K	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
1.1.3. Insulation Factor (E)		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
1.1.4. Inside Air Velocity (vair)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
1.1.5. Outside Air Velocity (on Ceiling), Vao	m/s	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
1.1.6. Inside Convective Heat Trans. Coef. (hi)	W/m2.K	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	
1.1.7. Outside Convective Heat Trans. Coef. (ho)	W/m2.K	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	
1.1.8. Thickness (xi)	m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1.1.9. Overall Heat Transfer Coefficient (U)	W/m2.K	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	
1.1.10. Ceiling Temperature	oC	23.0	22.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	31.0	33.0	33.0	34.0	33.0	32.0	31.0	30.0	29.0	27.0	26.0	25.0	24.0	
1.1.12. Heat Load	W	30.8	0.0	0.0	30.8	61.6	92.5	431.4	462.3	493.1	523.9	585.5	647.2	678.0	647.2	616.4	585.5	246.5	215.7	154.1	123.3	92.5	61.6	30.8	
<b>1.2. Wall Load</b>																									
1.2.1. Wall Surface Area (A)	m2	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	
1.2.2. Coefficient of Conductivity (ki)	W/m.K	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	
1.2.3. Thickness (xi)	m	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
1.2.5. Ambient Temp. (for Half Wall Area)	oC	25.5	24.5	24.5	25.5	26.5	27.5	28.5	29.5	30.5	31.5	33.5	35.5	35.5	36.5	35.5	34.5	33.5	32.5	31.5	29.5	28.5	27.5	26.5	
1.2.6. Air Vel. Over Surface in the Room (Vair)	m/s	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
1.2.7. Air vel. Over Surface Outside Room (Vao)	m/s	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
1.2.8. Outside Convective Heat Trans. Coef (ho)	W/m2.K	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	
1.2.9. Inside Convective Heat Trans. Coef (hi)	W/m2.K	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	
1.2.10. Overall Heat Transfer Coefficient (U)	W/m2.K	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
1.2.11. Wall Load	W	58.2	0.0	0.0	58.2	116.3	174.5	232.7	290.8	349.0	407.1	523.5	639.8	639.8	698.0	639.8	581.6	523.5	465.3	407.1	290.8	232.7	174.5	116.3	
1.2.12. Wall Load (for half wall area)	W	203.6	145.4	145.4	203.6	261.7	319.9	378.1	436.2	494.4	552.5	668.9	785.2	785.2	843.4	785.2	727.0	668.9	610.7	552.5	436.2	378.1	319.9	261.7	
1.2.13. Total Wall Load	W	261.7	145.4	145.4	261.7	378.1	494.4	610.7	727.0	843.4	959.7	1192.3	1425.0	1425.0	1541.3	1425.0	1308.7	1192.3	1076.0	959.7	727.0	610.7	494.4	378.1	
<b>1.3. Window Load</b>																									
1.3.3. Thickness (xi)	m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1.3.4. Ki (glass)	W/m.K	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
1.3.5. Window Surface Area (A)	m2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	
1.3.6. Air Vel. Over Surface in the Room (Vair)	m/s	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1.3.7. Air vel. Over Surface Outside Room (Vao)	m/s	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
1.3.8. Inside Convective Heat Trans. Coef (hi)	W/m2.K	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
1.2.9. Outside Convective Heat Trans. Coef (ho)	W/m2.K	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	
1.3.10. Overall Heat Transfer Coefficient (U)	W/m.K	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
1.3.11. Window Load	W	3.8	0.0	0.0	3.8	7.6	11.4	15.2	18.9	22.7	26.5	34.1	41.7	41.7	45.5	41.7	37.9	34.1	30.3	26.5	18.9	15.2	11.4	7.6	
<b>2. People Load</b>																									
2.1. Number of people in the room		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	3.0	3.0	3.0	0.0	3.0	3.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	
2.2. Estimate load for a person	W	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	
2.3. People Load	W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1050.0	1050.0	1050.0	1050.0	1050.0	0.0	1050.0	1050.0	1050.0	1050.0	0.0	0.0	0.0	0.0	0.0	0.0	
<b>3. Lighting Load</b>																									
3.1. Number of Light in the Room		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
3.2. Wattage	W	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
3.3. Lighting Load	W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	
Heat Load Upstairs (Per Room)	W	296.3	145.4	145.4	296.3	447.3	598.2	1057	2458.2	2609.2	2780.1	3062.0	3363.8	2313.8	3314.8	3363.8	3212.9	3062.0	1552.9	1201.9	900.1	749.1	598.2	447.3	
Subtotal Heat Load Upstairs (S2 Rooms)	KW	15.4	7.6	7.6	15.4	23.3	31.1	55.0	127.8	135.7	143.5	159.2	174.9	120.3	172.4	174.9	167.1	159.2	80.7	62.5	46.8	39.0	31.1	23.3	
Heat Load Downstairs (Per Room: T Ceilings+TRoom)	W	265.5	145.4	145.4	265.5	385.6	505.7	625.9	1996.0	2116.1	2236.2	2476.4	2716.6	1666.6	2636.8	2716.6	2596.5	2476.4	1306.3	986.2	746.0	625.9	505.7	385.6	
Subtotal Heat Load Downstairs (S2 Rooms)	KW	13.8	7.6	7.6	13.8	20.1	26.3	32.5	103.8	110.0	116.3	128.8	141.3	86.7	137.1	141.3	135.0	128.8	67.9	51.3	38.8	32.5	26.3	20.1	
Total Heat Load of UNTAET	KW	29.2	15.1	15.1	29.2	43.3	57.4	87.5	231.6	245.7	259.8	288.0	316.2	207.0	309.5	316.2	302.1	288.0	148.7	113.8	85.6	71.5	57.4	43.3	
Electricity Load (For Lighting & Computer)	KW	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
Electricity Load (For AC)	KW	13.3	6.9	6.9	13.3	19.7	26.1	39.8	105.3	111.7	118.1	130.9	143.7	94.1	140.7	143.7	137.3	130.9	67.6	51.7	38.9	32.5	26.1		
Total Electricity Load	KW	18.3	11.9	11.9	18.3	24.7	31.1	39.8	155.7	162.1	168.5	181.3	194.1	144.5	191.1	194.1	187.7	181.3	72.6	56.7	43.9	37.5	31.1		

**Appendix B2. Heat and Electricity Load Central Payment Office Buildings**

1. Surface Infiltration Heat Load	Unit	Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Ambient Temperature (T amb.)	oC	23	22	22	23	24	25	26	27	28	29	31	33	33	34	33	32	31	30	29	27	26	25	24	23
Inside Room Temperature (T Room)	oC	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
<b>1.1. Ceiling Load</b>																									
1.1.1. Ceiling Surface Area (A)	m <sup>2</sup>	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
1.1.2. Coefficient of conductivity (ki) for Plywood	W/m.K	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1.1.3. Insulation Factor (E)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.1.4. Inside Air Velocity (vai)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
1.1.5. Outside Air Velocity (on Ceiling), Vao	m/s	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
1.1.6. Inside Convective Heat Trans. Coef. (hi)	W/m <sup>2</sup> .K	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
1.1.7. Outside Convective Heat Trans. Coef. (ho)	W/m <sup>2</sup> .K	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19
1.1.8. Thickness (xi)	m	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1.1.9. Overall Heat Transfer Coefficient (U)	W/m <sup>2</sup> .K	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
1.1.10. Ceiling Temperature	oC	23.00	22.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00	31.00	33.00	33.00	34.00	33.00	32.00	31.00	30.00	29.00	27.00	26.00	25.00	24.00	23.00
1.1.12. Heat Load	W	30.82	0.00	0.00	30.82	61.64	92.45	123.26	154.07	184.88	215.69	246.50	277.31	308.12	338.93	369.74	400.55	431.36	462.17	492.98	523.79	554.60	585.41	616.22	647.03
<b>1.2. Wall Load</b>																									
1.2.1. Wall Surface Area (A)	m <sup>2</sup>	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
1.2.2. Coefficient of Conductivity (ki)	W/m.K	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
1.2.3. Thickness (xi)	m	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
1.2.5. Ambient Temp. (for Half Wall Area)	oC	25.50	24.50	24.50	25.50	26.50	27.50	28.50	29.50	30.50	31.50	33.50	35.50	35.50	36.50	35.50	34.50	33.50	32.50	31.50	29.50	28.50	27.50	26.50	25.50
1.2.6. Air Vel. Over Surface in the Room (Vai)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
1.2.7. Air vel. Over Surface Outside Room (Vao)	m/s	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
1.2.8. Outside Convective Heat Trans. Coef (ho)	W/m <sup>2</sup> .K	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13
1.2.9. Inside Convective Heat Trans. Coef (hi)	W/m <sup>2</sup> .K	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
1.2.10. Overall Heat Transfer Coefficient (U)	W/m <sup>2</sup> .K	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45
1.2.11. Wall Load	W	58.16	0.00	0.00	58.16	116.33	174.49	232.65	290.81	348.98	407.14	465.30	523.46	581.63	639.79	697.95	756.11	814.27	872.43	930.59	988.75	1046.91	1105.07	1163.23	1221.39
1.2.12. Wall Load (for half wall area)	W	203.57	145.41	145.41	203.57	261.73	319.89	378.06	436.22	494.38	552.55	610.71	668.87	727.03	785.19	843.36	901.52	959.68	1017.84	1076.00	1134.16	1192.32	1250.48	1308.64	1366.80
1.2.13. Total Wall Load	W	261.73	145.41	145.41	261.73	378.06	494.38	610.71	727.03	843.36	959.68	1076.00	1192.32	1308.64	1424.96	1541.28	1657.60	1773.92	1890.24	2006.56	2122.88	2239.20	2355.52	2471.84	2588.16
<b>1.3. Wall Load (Window)</b>																									
1.3.3. Thickness (xi)	m	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1.3.4. Ki (glass)	W/m.K	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
1.3.5. Window Surface Area (A)	m <sup>2</sup>	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
1.3.6. Air Vel. Over Surface in the Room (Vai)	m/s	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
1.3.7. Air vel. Over Surface Outside Room (Vao)	m/s	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
1.3.8. Inside Convective Heat Trans. Coef (hi)	W/m <sup>2</sup> .K	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01
1.2.9. Outside Convective Heat Trans. Coef (ho)	W/m <sup>2</sup> .K	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13
1.3.10. Overall Heat Transfer Coefficient (U)	W/m.K	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
1.3.11. Window Load	W	3.79	0.00	0.00	3.79	7.58	11.36	15.15	18.94	22.73	26.51	30.29	34.08	37.87	41.66	45.45	49.24	53.03	56.82	60.61	64.40	68.19	71.98	75.77	79.56
<b>2. People Load</b>																									
2.1. Number of people in the room		0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00	3.00	3.00	3.00	0.00	3.00	3.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.2. Estimate load for a person	W	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00
2.3. People Load	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1050.00	1050.00	1050.00	1050.00	1050.00	0.00	1050.00	1050.00	1050.00	1050.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>3. Lighting Load</b>																									
3.1. Number of Light in the Room		0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	2.00	2.00	2.00	0.00	2.00	2.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.2. Wattage	W	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
3.3. Lighting Load	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	200.00	200.00	200.00	200.00	200.00	0.00	200.00	200.00	200.00	200.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heat Load Upstair (Per Room)	W	296.34	145.41	145.41	296.34	447.27	598.20	749.13	900.06	1050.99	1201.92	1352.85	1503.78	1654.71	1805.64	1956.57	2107.50	2258.43	2409.36	2560.29	2711.22	2862.15	3013.08	3164.01	3314.94
Total Heat Load Upstair (10 Rooms)	KW	2.96	1.45	1.45	2.96	4.47	5.98	7.49	9.00	10.51	12.02	13.53	15.04	16.55	18.06	19.57	21.08	22.59	24.10	25.61	27.12	28.63	30.14	31.65	33.16
Heat Load Downstair (T Ceiling= T Room)	W	265.52	145.41	145.41	265.52	385.63	505.75	625.86	745.97	866.08	986.19	1106.30	1226.41	1346.52	1466.63	1586.74	1706.85	1826.96	1947.07	2067.18	2187.29	2307.40	2427.51	2547.62	2667.73
Subtotal Downstair Head Loads (10 Rooms)	KW	2.66	1.45	1.45	2.66	3.86	5.06	6.26	7.46	8.66	9.86	11.06	12.26	13.46	14.66	15.86	17.06	18.26	19.46	20.66	21.86	23.06	24.26	25.46	26.66
Total Heat Load of CPO	KW	5.62	2.91	2.91	5.62	8.33	11.04	13.75	16.46	19.17	21.88	24.59	27.30	30.01	32.72	35.43	38.14	40.85	43.56	46.27	48.98	51.69	54.40	57.11	59.82
Electricity Load (For Air Conditioning, COP=2.2)	KW	2.55	1.32	1.32	2.55	3.79	5.02	6.25	7.48	8.71	9.94	11.17	12.40	13.63	14.										

**Appendix B3. Heat Load and Electricity Load of The National University of East Timor (UNATIL) Building**

	Unit	Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<b>1. Surface Infiltration Heat Load</b>																									
Ambient Temperature (T amb.)	oC	23	22	22	23	24	25	26	27	28	29	31	33	33	34	33	32	31	30	29	27	26	25	24	23
Inside Room Temperature (T Room)	oC	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
<b>1.1. Ceiling Load</b>																									
1.1.1. Ceiling Surface Area (A)	m <sup>2</sup>	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	
1.1.2. Coefficient of conductivity (ki) for Plywood	W/m.K	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	
1.1.3. Insulation Factor (E)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.1.4. Inside Air Velocity (vai)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
1.1.5. Outside Air Velocity (on Ceiling), Vao	m/s	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
1.1.6. Inside Convective Heat Trans. Coef. (hi)	W/m <sup>2</sup> .K	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	
1.1.7. Outside Convective Heat Trans. Coef. (ho)	W/m <sup>2</sup> .K	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	
1.1.8. Thickness (xi)	m	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
1.1.9. Overall Heat Transfer Coefficient (U)	W/m <sup>2</sup> .K	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	
1.1.10. Ceiling Temperature	oC	23.00	22.00	22.00	23.00	24.00	25.00	36.00	37.00	38.00	39.00	41.00	43.00	43.00	44.00	43.00	42.00	41.00	30.00	29.00	27.00	26.00	25.00	24.00	23.00
1.1.12. Heat Load	W	30.82	0.00	0.00	30.82	61.64	92.45	431.45	462.27	493.08	523.90	585.54	647.17	647.17	677.99	647.17	616.36	585.54	246.54	215.72	154.09	123.27	92.45	61.64	30.82
<b>1.2. Wall Load</b>																									
1.2.1. Wall Surface Area (A)	m <sup>2</sup>	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	
1.2.2. Coefficient of Conductivity (ki)	W/m.K	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	
1.2.3. Thickness (xi)	m	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
1.2.5. Ambient Temp. (for Half Wall Area)	oC	25.50	24.50	24.50	25.50	26.50	27.50	28.50	29.50	30.50	31.50	33.50	35.50	35.50	36.50	35.50	34.50	33.50	32.50	31.50	29.50	28.50	27.50	26.50	25.50
1.2.6. Air Vel. Over Surface in the Room (Vai)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
1.2.7. Air vel. Over Surface Outside Room (Vao)	m/s	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
1.2.8. Outside Convective Heat Trans. Coef (ho)	W/m <sup>2</sup> .K	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	
1.2.9. Inside Convective Heat Trans. Coef (hi)	W/m <sup>2</sup> .K	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	
1.2.10. Overall Heat Transfer Coefficient (U)	W/m <sup>2</sup> .K	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	
1.2.11. Wall Load	W	58.16	0.00	0.00	58.16	116.33	174.49	232.65	290.81	348.98	407.14	523.46	639.79	639.79	697.95	639.79	581.63	523.46	465.30	407.14	290.81	232.65	174.49	116.33	58.16
1.2.12. Wall Load (for half wall area)	W	203.57	145.41	145.41	203.57	261.73	319.89	378.06	436.22	494.38	552.55	668.87	785.20	785.20	843.36	785.20	727.03	668.87	610.71	552.55	436.22	378.06	319.89	261.73	203.57
1.2.13. Total Wall Load	W	261.73	145.41	145.41	261.73	378.06	494.38	610.71	727.03	843.36	959.68	1192.34	1424.99	1424.99	1541.31	1424.99	1308.66	1192.34	1076.01	959.68	727.03	610.71	494.38	378.06	261.73
<b>1.3. Wall Load (Window)</b>																									
1.3.3. Thickness (xi)	m	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
1.3.4. Ki (glass)	W/m.K	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	
1.3.5. Window Surface Area (A)	m <sup>2</sup>	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	
1.3.6. Air Vel. Over Surface in the Room (Vai)	m/s	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	
1.3.7. Air vel. Over Surface Outside Room (Vao)	m/s	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
1.3.8. Inside Convective Heat Trans. Coef (hi)	W/m <sup>2</sup> .K	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	
1.2.9. Outside Convective Heat Trans. Coef (ho)	W/m <sup>2</sup> .K	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	
1.3.10. Overall Heat Transfer Coefficient (U)	W/m.K	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	
1.3.11. Window Load	W	3.79	0.00	0.00	3.79	7.58	11.36	15.15	18.94	22.73	26.51	34.09	41.66	41.66	45.45	41.66	37.88	34.09	30.30	26.51	18.94	15.15	11.36	7.58	3.79
<b>2. People Load</b>																									
2.1. Number of people in the room		0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00	3.00	3.00	3.00	0.00	3.00	3.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.2. Estimate load for a person	W	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	0.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00
2.3. People Load	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1050.00	1050.00	1050.00	1050.00	1050.00	0.00	1050.00	1050.00	1050.00	1050.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>3. Lighting Load</b>																									
3.1. Number of Light in the Room		0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	2.00	2.00	2.00	0.00	2.00	2.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.2. Wattage	W	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
3.3. Lighting Load	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	200.00	200.00	200.00	200.00	200.00	0.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
Heat Load Upstair (Per Room)	W	296.34	145.41	145.41	296.34	447.27	598.20	1057.3	2458.24	2609.17	2760.10	3061.96	3363.82	2313.82	3314.75	3363.82	3212.89	3061.96	1552.85	1201.92	900.06	749.13	598.20	447.27	296.34
Subtotal Heat Load Upstair (5 Rooms)	KW	1.48	0.73	0.73	1.48	2.24	2.99	5.29	12.29	13.05	15.31	16.82	11.57	16.57	16.82	16.06	15.31	7.76	6.01	4.50	3.75	2.99	2.24	1.48	
Heat Load Downstair (T Ceiling=T Room)	W	265.52	145.41	145.41	265.52	385.63	505.75	625.86	1995.97	2116.08	2236.20	2476.42	2716.65	1686.65	2636.76	2716.65	2596.54	2476.42	1306.31	986.20	745.97	625.86	505.75	385.63	265.52
Subtotal Heat Load Downstair (7 Rooms)	KW	1.86	1.02	1.02	1.86	2.70	3.54	4.38	13.97	14.81	15.65	17.33	19.02	11.67	18.46	19.02	18.18	17.33	9.14	6.90	5.22	4.38	3.54	2.70	1.86
<b>Total Heat Loads of UNATIL</b>	KW	3.34	1.74	1.74	3.34																				

**Appendix B4. Heat and Electricity Load of Hello Mister Building**

1. Surface Infiltration Heat Load		Unit	Hour																								
Time	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Ambient Temperature (T amb)	oC	23	22	22	23	24	25	26	27	28	29	31	33	33	34	33	32	31	30	29	27	26	25	24	23		
Inside Room Temperature (T Room)	oC	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22		
<b>1.1. Ceiling Load</b>																											
<b>1.1.1. Ceiling Surface Area (A)</b>																											
1.1.1.1. Ceiling Surface Area (A)	m <sup>2</sup>	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72		
1.1.1.2. Coefficient of conductivity (k) for Plywood	W/m.K	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12		
1.1.1.3. Insulation Factor (E)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1.1.1.4. Inside Air Velocity (v ai)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		
1.1.1.5. Outside Air Velocity (on Ceiling), V ao	m/s	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50		
1.1.1.6. Inside Convective Heat Trans. Coef. (h i)	W/m <sup>2</sup> .K	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41		
1.1.1.7. Outside Convective Heat Trans. Coef. (h o)	W/m <sup>2</sup> .K	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19		
1.1.1.8. Thickness (b i)	m	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02		
1.1.1.9. Overall Heat Transfer Coefficient (U)	W/m <sup>2</sup> .K	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28		
1.1.1.10. Ceiling Temperature	oC	23	22	22	23	24	25	26	27	28	29	31	33	33	34	33	32	31	30	29	27	26	25	24	23		
1.1.12. Heat Load	W	92.45	0.00	0.00	92.45	184.91	277.36	1294.35	1386.80	1479.25	1571.71	1756.61	1941.52	1941.52	2033.97	1941.52	1849.07	1756.61	739.63	647.17	462.27	369.61	277.36	184.91	92.45		
<b>1.2. Wall Load</b>																											
<b>1.2.1. Wall Surface Area (A)</b>																											
1.2.1.1. Wall Surface Area (A)	m <sup>2</sup>	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00		
1.2.1.2. Coefficient of Conductivity (k)	W/m.K	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10		
1.2.1.3. Thickness (b i)	m	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		
1.2.1.5. Ambient Temp. (for Half Wall Area)	oC	25.50	24.50	24.50	24.50	26.50	27.50	28.50	29.50	30.50	31.50	33.50	35.50	35.50	36.50	35.50	34.50	33.50	32.50	31.50	29.50	28.50	27.50	26.50	25.50		
1.2.1.6. Air Vel. Over Surface in the Room (V ai)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		
1.2.1.7. Air vel. Over Surface Outside Room (V ao)	m/s	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00		
1.2.1.8. Outside Convective Heat Trans. Coef (h o)	W/m <sup>2</sup> .K	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13		
1.2.1.9. Inside Convective Heat Trans. Coef (h i)	W/m <sup>2</sup> .K	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41		
1.2.1.10. Overall Heat Transfer Coefficient (U)	W/m <sup>2</sup> .K	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45		
1.2.1.11. Wall Load	W	104.69	0.00	0.00	104.69	209.39	314.08	418.77	523.46	628.16	732.85	942.24	1151.62	1151.62	1256.31	1151.62	1046.93	942.24	837.54	732.85	628.16	523.46	418.77	314.08	209.39		
1.2.1.12. Wall Load (for half wall area)	W	366.42	261.73	261.73	366.42	471.12	575.81	680.50	785.20	889.89	994.58	1203.97	1413.35	1413.35	1518.05	1413.35	1308.66	1203.97	1099.27	994.58	889.89	785.20	680.50	575.81	471.12		
1.2.1.13. Total Wall Load	W	471.12	261.73	261.73	471.12	680.50	889.89	1099.27	1308.66	1518.05	1727.43	2146.20	2564.97	2564.97	2774.36	2564.97	2355.59	2146.20	1936.82	1727.43	1518.05	1308.66	1099.27	889.89	680.50		
<b>1.3. Window Load</b>																											
<b>1.3.1. Thickness (b i)</b>																											
1.3.1.1. Thickness (b i)	m	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		
<b>1.3.4. K i (glass)</b>																											
1.3.4.1. K i (glass)	W/m.K	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78		
<b>1.3.5. Window Surface Area (A)</b>																											
1.3.5.1. Window Surface Area (A)	m <sup>2</sup>	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50		
<b>1.3.6. Air Vel. Over Surface in the Room (V ai)</b>																											
1.3.6.1. Air Vel. Over Surface in the Room (V ai)	m/s	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		
<b>1.3.7. Air vel. Over Surface Outside Room (V ao)</b>																											
1.3.7.1. Air vel. Over Surface Outside Room (V ao)	m/s	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00		
<b>1.3.8. Inside Convective Heat Trans. Coef (h i)</b>																											
1.3.8.1. Inside Convective Heat Trans. Coef (h i)	W/m <sup>2</sup> .K	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01		
<b>1.3.9. Outside Convective Heat Trans. Coef (h o)</b>																											
1.3.9.1. Outside Convective Heat Trans. Coef (h o)	W/m <sup>2</sup> .K	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13		
<b>1.3.10. Overall Heat Transfer Coefficient (U)</b>																											
1.3.10.1. Overall Heat Transfer Coefficient (U)	W/m.K	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80		
1.3.11. Window Load	W	8.12	0.00	0.00	8.12	16.23	24.35	32.47	40.58	48.70	56.81	73.05	89.28	89.28	97.40	89.28	81.16	73.05	64.93	56.81	48.70	40.58	32.47	24.35	16.23		
<b>1.4. Door Load</b>																											
<b>1.4.1. Door cross-sectional Area</b>																											
1.4.1.1. Door cross-sectional Area	m <sup>2</sup>	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00		
<b>1.4.2. Relative Humidity</b>																											
1.4.2.1. Relative Humidity	%	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00		
<b>1.4.3. Inside Density</b>																											
1.4.3.1. Inside Density	kg/m <sup>3</sup>	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19		
<b>1.4.4. Outside Density</b>																											
1.4.4.1. Outside Density	kg/m <sup>3</sup>	1.19	1.19	1.19	1.19	1.18	1.18	1.17	1.17	1.16	1.15	1.15	1.14	1.15	1.15	1.16	1.16	1.16	1.17	1.18	1.18	1.18	1.18	1.18	1.19		
<b>1.4.5. Door Height</b>																											
1.4.5.1. Door Height	m	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
<b>1.4.6. Door Correction Factor (P2.30)</b>																											
1.4.6.1. Door Correction Factor (P2.30)		0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50		
<b>1.4.7. Air Velocity (V a)</b>																											
1.4.7.1. Air Velocity (V a)	m/s	0.01	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.11	0.11	0.13	0.11	0.10	0.09	0.08	0.07	0.05	0.04	0.03	0.02	0.01		
<b>1.4.8. Instantaneous Volumetric Air Flow (Q i)</b>																											
1.4.8.1. Instantaneous Volumetric Air Flow (Q i)	m <sup>3</sup> /s	0.03	0.00	0.00	0.03	0.06	0.09	0.11	0.15	0.17	0.21	0.27	0.33	0.33	0.38	0.33	0.31	0.27	0.24	0.21	0.15	0.11	0.09	0.06	0.03		
<b>1.4.9. Enthalpy of Inside Air (22 oC, 70% Humid.)</b>																											
1.4.9.1. Enthalpy of Inside Air (22 oC, 70% Humid.)	J/kg	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000	152000		
<b>1.4.10. Enthalpy of Outside Air (At T amb.)</b>																											
1.4.10.1. Enthalpy of Outside Air (At T amb.)	J/kg	157000	152000	152000	152000	161000	165000	168000	172000																		



**Appendix B6. Heat and Electricity Load of the Regent Hotel Building**

	Unit	Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<b>1. Surface Infiltration Heat Load</b>																									
Ambient Temperature (T amb.)	oC	23	22	22	23	24	25	26	27	28	29	31	33	33	34	33	32	31	30	29	27	26	25	24	23
Inside Room Temperature (T Room)	oC	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
<b>1.1. Ceiling Load</b>																									
1.1.1. Ceiling Surface Area (A)	m <sup>2</sup>	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
1.1.2. Coefficient of conductivity (ki) for Plywood	W/m.K	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	
1.1.3. Insulation Factor (E)		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1.1.4. Inside Air Velocity (vai)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
1.1.5. Outside Air Velocity (on Ceiling), Vao	m/s	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
1.1.6. Inside Convective Heat Trans. Coef. (hi)	W/m <sup>2</sup> .K	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	
1.1.7. Outside Convective Heat Trans. Coef. (ho)	W/m <sup>2</sup> .K	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	
1.1.8. Thickness (xi)	m	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
1.1.9. Overall Heat Transfer Coefficient (U)	W/m <sup>2</sup> .K	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	
1.1.10. Ceiling Temperature	oC	23	22	22	23	24	25	26	27	28	29	31	33	33	34	33	32	31	30	29	27	26	25	24	
1.1.12. Heat Load	W	15.41	0.00	0.00	15.41	30.82	46.23	215.72	231.13	246.54	261.95	292.77	323.59	323.59	339.00	323.59	308.18	292.77	123.27	107.86	77.04	61.64	46.23	30.82	
<b>1.2. Wall Load</b>																									
1.2.1. Wall Surface Area (A)	m <sup>2</sup>	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	
1.2.2. Coefficient of Conductivity (ki)	W/m.K	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	
1.2.3. Thickness (xi)	m	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
1.2.5. Ambient Temp. (for Half Wall Area)	oC	25.5	24.5	24.5	25.5	26.5	27.5	28.5	29.5	30.5	31.5	33.5	35.5	35.5	36.5	35.5	34.5	33.5	32.5	31.5	29.5	28.5	27.5	26.5	
1.2.6. Air Vel. Over Surface in the Room (Vai)	m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
1.2.7. Air vel. Over Surface Outside Room (Vao)	m/s	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
1.2.8. Outside Convective Heat Trans. Coef (ho)	W/m <sup>2</sup> .K	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	
1.2.9. Inside Convective Heat Trans. Coef (hi)	W/m <sup>2</sup> .K	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	
1.2.10. Overall Heat Transfer Coefficient (U)	W/m <sup>2</sup> .K	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	
1.2.11. Wall Load	W	40.71	0.00	0.00	40.71	81.43	122.14	162.86	203.57	244.28	285.00	366.42	447.85	447.85	488.57	447.85	407.14	366.42	325.71	285.00	203.57	162.86	122.14	81.43	
1.2.12. Wall Load (for half wall area)	W	142.50	101.78	101.78	142.50	183.21	223.93	264.64	305.35	346.07	386.78	468.21	549.64	549.64	589.92	549.64	508.92	468.21	427.50	386.78	305.35	264.64	223.93	183.21	
1.2.13. Total Wall Load	W	183.21	101.78	101.78	183.21	264.64	346.07	427.50	508.92	590.35	671.78	834.63	997.49	997.49	1078.92	997.49	916.06	834.63	753.21	671.78	508.92	427.50	346.07	264.64	
<b>1.3. Window Load</b>																									
1.3.3. Thickness (xi)	m	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
1.3.4. Ki (glass)	W/m.K	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	
1.3.5. Window Surface Area (A)	m <sup>2</sup>	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
1.3.6. Air Vel. Over Surface in the Room (Vai)	m/s	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1.3.7. Air vel. Over Surface Outside Room (Vao)	m/s	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
1.3.8. Inside Convective Heat Trans. Coef (hi)	W/m <sup>2</sup> .K	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	
1.3.9. Outside Convective Heat Trans. Coef (ho)	W/m <sup>2</sup> .K	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	22.13	
1.3.10. Overall Heat Transfer Coefficient (U)	W/m.K	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	
1.3.11. Window Load	W	3.25	0.00	0.00	3.25	6.49	9.74	12.99	16.23	19.48	22.73	29.22	35.71	35.71	38.96	35.71	32.47	29.22	25.97	22.73	16.23	12.99	9.74	6.49	
<b>2. People Load</b>																									
2.1. Number of people in the room		1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	1	1	1	1	1	1	
2.2. Estimate load for a person	W	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	
2.3. People Load	W	350	350	350	350	350	350	350	0	0	0	0	350	350	0	0	0	0	350	350	350	350	350	350	
<b>3. Lighting Load</b>																									
3.1. Number of Light in the Room		0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	2	2	2	2	0	0	
3.2. Wattage	W	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
3.3. Lighting Load	W	0	0	0	0	0	0	0	0	0	0	0	200	200	0	0	0	0	200	200	200	200	0	0	
Heat Load Upstair (Per Room)	W	551.87	451.78	451.78	551.87	651.95	752.03	1006.2	756.29	856.37	956.46	1156.62	1906.79	1906.79	1456.87	1356.79	1256.71	1156.62	1452.45	1352.37	1152.20	1052.12	752.03	651.95	
Subtotal Heat Load Upstair (20 Rooms)	kW	11.04	9.04	9.04	11.04	13.04	15.04	20.12	15.13	17.13	19.13	23.13	38.14	38.14	29.14	27.14	25.13	23.13	29.05	27.05	23.04	21.04	15.04	13.04	
Downstair Heat Load (T Ceiling=T Room)	kW	536.46	451.78	451.78	536.46	621.13	705.81	790.48	525.16	609.83	694.50	863.85	1583.20	1583.20	1117.88	1033.20	948.53	863.85	1329.18	1244.50	1075.16	990.48	705.81	621.13	
Subtotal Heat Load Downstair (20 Rooms)	kW	10.73	9.04	9.04	10.73	12.42	14.12	15.81	10.50	12.20	13.89	17.28	31.66	31.66	22.36	20.66	18.97	17.28	26.58	24.89	21.50	19.81	14.12	12.42	
Total Heat Load	kW	11.05	9.04	9.04	11.05	13.05	15.05	20.14	15.14	17.14	19.14	23.15	38.17	38.17	29.16	27.16	25.15	23.15	29.08	27.07	23.07	21.06	15.05	13.05	
Electricity Load (For Air Conditioning)	kW	5.02	4.11	4.11	5.02	5.93	6.84	9.15	6.88	7.79	8.70	10.52	17.35	17.35	13.25	12.34	11.43	10.52	13.22	12.31	10.48	9.57	6.84	5.93	
Electricity Load (For Fan, Computer, Lighting & Refrig)	kW	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	
Total Electricity Load	kW	17.52	16.61	16.61	17.52	18.43	19.34	21.65	19.38	20.29	21.20	23.02	29.85	29.85	25.75	24.84	23.93	23.02	25.72	24.81	22.98	22.07	19.34	18.43	

**Appendix B7. Total Heat and Electricity Loads of Selected Buildings**

Buildings	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Regent Hotel	Heat Loads	KW	21.74	18.07	18.07	21.74	25.40	29.07	32.74	25.19	28.86	32.52	39.86	69.19	69.19	50.86	47.19	43.52	39.86	55.40	51.73	44.40	40.74	29.07	25.40	21.74
	Electricity Load (For Air Conditioning, COP=2.2)	KW	9.88	8.21	8.21	9.88	11.55	13.21	14.88	11.45	13.12	14.78	18.12	31.45	31.45	23.12	21.45	19.78	18.12	25.18	23.52	20.18	18.52	13.21	11.55	9.88
	Electricity Load (For Computer & Lighting)	KW	5.70	5.70	5.70	5.70	5.70	4.00	8.00	8.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	9.70	9.70	9.70	9.70	5.70	5.70	5.70
UNTAET	Heat Loads	KW	29.07	15.12	15.12	29.07	43.01	56.95	70.89	229.35	243.29	257.24	285.12	313.01	203.81	306.15	313.01	299.07	285.12	147.47	112.72	84.84	70.89	56.95	43.01	29.07
	Electricity Load (For Computer & Lighting)	KW	5.00	5.00	5.00	5.00	5.00	5.00	0.00	50.40	50.40	50.40	50.40	50.40	0.00	50.40	50.40	50.40	50.40	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	Electricity Load (For Air Conditioning, COP=2.2)	KW	13.21	6.87	6.87	13.21	19.55	25.89	32.22	104.25	110.59	116.93	129.60	142.28	92.64	139.16	142.28	135.94	129.60	67.03	51.24	38.56	32.22	25.89	19.55	13.21
UNATIL	Heat Loads	KW	3.33	1.74	1.74	3.33	4.91	6.49	8.07	26.04	27.63	29.21	32.37	35.53	22.93	34.71	35.53	33.95	32.37	16.79	12.81	9.65	8.07	6.49	4.91	3.33
	Electricity Load (For Air Conditioning, COP=2.2)	KW	1.51	0.79	0.79	1.51	2.23	2.95	3.67	11.84	12.56	13.28	14.71	16.15	10.42	15.78	16.15	15.43	14.71	7.63	5.82	4.39	3.67	2.95	2.23	1.51
	Electricity Load (For Computer & Lighting)	KW	2.50	2.50	2.50	2.50	2.50	2.50	0.00	0.00	21.20	21.20	21.20	21.20	0.00	21.20	21.20	21.20	1.20	2.50	2.50	2.50	2.50	2.50	2.50	2.50
CPO	Heat Loads	KW	5.59	2.91	2.91	5.59	8.27	10.95	13.63	44.11	46.79	49.47	54.83	60.19	39.19	58.88	60.19	57.51	54.83	28.36	21.88	16.31	13.63	10.95	8.27	5.59
	Electricity Load (For Air Conditioning, COP=2.2)	KW	2.54	1.32	1.32	2.54	3.76	4.98	6.20	20.05	21.27	22.49	24.92	27.36	17.82	26.76	27.36	26.14	24.92	12.89	9.85	7.42	6.20	4.98	3.76	2.54
	Electricity Load (For Computer & Lighting)	KW	1.00	1.00	1.00	1.00	1.00	1.00	0.00	4.00	8.00	8.00	8.00	8.00	0.00	8.00	8.00	8.00	8.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BNU	Heat Loads	KW	8.38	4.36	4.36	8.38	12.41	16.43	20.45	66.16	70.18	74.20	82.25	90.29	58.79	88.31	90.29	86.27	82.25	42.54	32.52	24.47	20.45	16.43	12.41	8.38
	Electricity Load (For Air Conditioning, COP=2.2)	KW	3.81	1.98	1.98	3.81	5.64	7.47	9.30	30.07	31.90	33.73	37.38	41.04	26.72	40.14	41.04	39.21	37.38	19.34	14.78	11.12	9.30	7.47	5.64	3.81
	Electricity Load (For Computer & Lighting)	KW	1.50	1.50	1.50	1.50	1.50	1.50	0.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Hello Mister	Heat Loads	KW	9.46	1.57	1.57	3.46	6.26	9.60	13.23	60.68	96.43	103.99	119.58	138.39	138.39	125.79	113.19	145.91	136.38	110.95	72.49	21.38	15.63	12.00	8.66	5.86
	Electricity Load (For Air Conditioning, COP=2.2)	KW	4.30	0.71	0.71	1.57	2.85	4.36	6.01	27.58	43.83	47.27	54.35	62.91	62.91	57.18	51.45	66.32	61.99	50.43	32.95	9.72	7.10	5.46	3.94	2.67
	Electricity Load (For Computer, Lighting & Refrigerator)	KW	21.20	21.20	21.20	21.20	21.20	21.20	20.00	20.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	21.20	21.20	21.20	21.20	21.20	21.20	21.20
<b>Total Working Day Heat Load</b>		KW	77.57	43.78	43.78	71.57	100.26	129.49	159.01	451.53	513.18	546.63	614.01	706.61	532.31	664.69	659.41	666.23	630.81	401.51	303.95	201.06	169.41	131.89	102.68	73.97
<b>Total Weekend Heat Load</b>		KW	21.01	11.06	11.06	15.01	19.86	25.25	30.93	75.88	113.68	123.30	142.99	177.47	177.47	155.36	140.72	171.38	159.79	141.07	100.56	45.34	37.53	27.65	22.26	17.41
<b>Total Electricity Load</b>		KW	76.73	59.18	59.18	74.00	89.24	103.02	111.43	339.73	389.94	407.34	442.36	488.83	320.83	468.70	467.38	468.29	429.99	246.61	196.80	145.64	129.06	105.81	90.33	75.09
<b>Absorption Chiller (Single-Stage)</b>		KW	119.33	67.35	67.35	110.10	154.24	199.22	244.63	694.66	789.50	840.97	944.62	1087.09	818.93	1022.60	1014.47	1024.96	970.47	617.71	467.62	309.32	260.63	202.91	157.94	113.79
<b>Absorption Chiller (Double-Stage)</b>		KW	73.87	41.69	41.69	68.16	95.48	123.32	151.44	430.03	488.74	520.60	584.77	672.96	506.96	633.04	628.01	634.50	600.77	382.39	289.48	191.48	161.34	125.61	97.77	70.44