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THK-AELE-45

5 July 1999

Sr. Julio Zúñiga
Atlas Eléctrica S.A.
KM 9 Ruta Nacional No. 1
Contiguo a la Entrada del Residencial Los Lagos

Dear Sr. Zúñiga,

Enclosed is our report entitled Energy Conservation at Atlas Eléctrica through Lighting. It was written at Atlas Eléctrica during the period 17 May through 5 July 1999. Preliminary work was completed in Worcester, Massachusetts, prior to our arrival in Costa Rica. A copy of this report is simultaneously being submitted to Professor Keil for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. We appreciate the time in which you have devoted to us.

Sincerely,

Rebecca Coury

Sonja Farak

Makoto Waseda

Report Submitted to:

Dr. Thomas H. Keil

Costa Rica, Project Center

By

Rebecca Coury ____________________

Sonja Farak ____________________

Makoto Waseda ____________________

In Cooperation With

Julio Zúñiga

Atlas Eléctrica, S.A.

ENERGY CONSERVATION AT ATLAS ELÉCTRICA THROUGH LIGHTING

July 5, 1999

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of Atlas Eléctrica or Worcester Polytechnic Institute.

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Abstract

This report was prepared for Atlas Eléctrica, S.A., in Heredia, Costa Rica, to provide them with a plan for a more efficient lighting system in their factory. Their current lighting structure was evaluated and alternative lighting methods were researched. These methods included various types of light bulbs as well as the placement and material of skylights. This project provides Atlas Eléctrica with a plan for the designing of lighting systems when they expand their factory.

Authorship Page

This report was written through the combined efforts of Rebecca Coury, Sonja Farak, and Makoto Waseda. The section on lighting, explaining the different types of bulbs, was mainly written by Rebecca Coury. Sonja Farak wrote most of the section on conservation methods and Makoto Waseda took all the measurements of the area of the factory and drew the AutoCAD figures. The rest of the report was a combined group effort.

Acknowledgements

While working on this project, we had the opportunity to work with many people. We would like to thank Pablo Solís for showing us around the Atlas factory. We would also like to thank Edwin Cardoza and Leonardo Quirós for sharing their office with us. We would like to extend a special thank you to Julio Zúñiga for getting us in contact with people in the company and providing us with the information we needed. In addition to the people at Atlas Eléctrica, we would like to thank Julio Aguilar at Baxter Healthcare International for proving us with information.

Executive Summary

Between 17 May and 5 July 1999, we worked on site with the engineering and maintenance departments of Atlas Eléctrica, S.A. to complete the project Energy Conservation at Atlas Eléctrica through Lighting. Atlas Eléctrica is a private Costa Rican manufacturing company with thirty-eight years of experience. The company specializes in major kitchen appliances, producing 400 refrigerators and 350 ranges a day. Due to the rising cost of electricity and the concern for an increased quality of production, Atlas wanted to optimize the lighting at the workstations throughout the factory. They wanted to use an efficient lighting system that would still provide adequate light for the workers. Atlas hoped that the new system would be adaptable to future additions to the factory as well as to their current layout.

In order to reduce electrical consumption, we had to evaluate the present lighting system. This evaluation included taking a variety of measurements as well as learning about alternative lighting options. First, we divided the factory into 15 self-contained sections. This allowed us to divide the factory into areas where similar tasks were performed throughout the area. We then counted the total number of lights that were in use at each of the workstations. These counts included both the fluorescent and sodium bulbs. Not only was the number of lights in use recorded, but also the total number of lights in each section was counted and their locations noted. We also took measurements of light intensity readings around the factory. A representative spot from each section was chosen to perform these readings. This spot appeared to have the average amount of light in the section. The readings were done by using a light meter that recorded the brightness of each section. This data, along with the light count data, were repeated three

times to ensure accurate results. The data were also collected during four different time intervals throughout the day. The first time period was in the morning between 9:00 a.m. and 11:00 a.m. The next time period was during the midday, or between 12:00 p.m. and 2:00 p.m. The third set of readings was taken in the afternoon between 3:00 p.m. and 4:00 p.m. The final time period was between 5:00 and 6:00 in the evening. These four time periods were chosen because they represent the times when different amounts of natural light was present in the factory. Besides counting the number of lights and measuring the light intensity readings, we took an inventory of the skylights in the factory. This inventory not only recorded the number of skylights present but also marked the location of the skylights. With this data, we were able to construct AutoCAD drawings of the factory that showed where the artificial lights and skylights were positioned. Next, we were shown where all of the light control boxes were. At each box, we turned each switch on and off to determine which lights were controlled by which switch. This task was very tedious as none of the switches were labeled and the switches were not in a logical order. We also researched lighting alternatives. These alternatives included different types of light bulbs, skylight materials, and lighting controls. We took into account the cost of the product, the energy efficiency of the product, and the quality of light the product produces. From this information, we determined the most efficient and highest quality light for the factory.

While trying to improve the quality of light at the workstations, we formulated an alternate way of lighting the plant. We took into consideration the amount of light needed at workstations as well as the efficiency of the lights. We also took into consideration the possibility of using natural light through skylights. Using skylights would allow there to be more light in the plant without using more electricity. Natural light also provides a better quality of light than artificial light, so this method of saving energy does not compromise the quality of light produced. The new scheme involves placing the bulbs in parallel rows instead of at right angles of each other and keeping the bulbs spaced out instead of crowding them together. It also involves the installation of skylights in areas where a high quality or amount of light is needed by the worker.

We made five recommendations for reducing their energy and improving their lighting. These recommendations involved changing of the type of bulb that they used to a more efficient bulb. They also included suggestions on different control mechanisms for the lights. These controls included different types of sensors and labeling the light switches. Another way we suggested reducing the energy was the installation of skylights. We also provided them with a more efficient lighting pattern. To improve the quality of their lighting, we advised them to construct a regular maintenance plan. This plan included changing the burned out bulbs as well as cleaning the lights.

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Chapter I.

Introduction

This report was prepared by three students at the Worcester Polytechnic Institute (WPI) Costa Rica Project Center in conjunction with Atlas Industrial S.A., a subsidiary of Atlas Eléctrica. The relationship of the Project Center with Atlas Eléctrica and information about Atlas Eléctrica are presented in Appendix A.

The major goal of this project was to reduce the energy consumption at Atlas Industrial S.A., thereby lowering electricity costs. As a major appliance manufacturer, Atlas uses a great deal of electricity in the physical production of appliances as well as in general operating procedures. Atlas spent 8,000,000 colones (US $29,000) per month on electricity and believes that this is too much. Although Atlas knows they spend too much on electricity, they have not previously implemented any plans for reducing their costs.

There were two specific objectives of this project. First, Atlas Eléctrica wanted to reduce its total electricity consumption. We specifically focused on the lighting used at Atlas to reduce a part of their electric consumption. This part of the project plan involved recommending simple procedures such as switching to light bulbs that are more efficient and making sure lights not in use are turned off. The second goal was to improve working conditions in the factory by improving lighting. Specifically we make recommendations about adjusting the amount of lighting over the working areas and reducing the number of areas in total darkness. We also explore forms of natural light that do not increase the temperature in the factory.

Our methodology began with us talking to the engineers and plant management about the lighting in the factory. We then took counts of the different lights on throughout the factory. We also measured the different amount of light in each section of the factory. Finally, we researched different lighting materials and technologies. We studied different types of light bulbs, different types of light arrangements, and different types of controls for the lights.

Our results are presented in both a cost-benefit analysis and an optimal lighting analysis. We studied the different costs for each kind of bulb and compared them with the benefits that the new bulbs would have on the working environment. We also studied optimal lighting for workstations and aisles. We included these measures in our recommendations.

This project was performed to fulfill the requirements of an Interactive Qualifying Project, or IQP, at Worcester Polytechnic Institute in Worcester, MA. The goal of any IQP is to integrate technology or science with society. This project successfully accomplished this integration. The technology side included the actual conservation of energy and reduction of electric power. The societal side was attained by three factors. First, the people within Atlas Eléctrica need to understand why and how to conserve electricity in their everyday work environment. All the planning and design in the world will not accomplishing anything unless appropriate procedures are carried out. Second, the consumption of energy has a direct effect on the environment. When electrical energy is conserved, the environment also benefits, as fewer pollutants are generated. Another way to help preserve the integrity of the environment is using alternative energy sources, such as natural light. Finally, by providing a better working environment, we propose plans for a safer and more productive factory.

Chapter II

Literature Review

Chapter II.

Literature Review

2.1 Introduction

In this review of the research literature on electrical conservation, a number of related topics are examined. First, a brief discussion of energy policy is included to describe the rough guidelines followed in Latin America. Atlas Eléctrica's energy use is examined to uncover the areas that need improvement. Next, different types of lighting equipment are discussed. These include different types of light bulbs, ballasts and fixtures, and light controls. General conservation methods, which apply to Atlas, are also discussed. The possible benefits of these methods are provided. To fully investigate the issue of conservation, alternate sources of energy are also discussed.

2.2 Policy

Energy production and consumption in Latin America represents only a small percentage of the world's total energy production and consumption. However, the past few decades, this percentage has increased rapidly. During this time, the Latin American energy system has also evolved positively in regards to environmental concerns. For example, the share of oil use in primary energy consumption dropped 13% (63% to 50%) between 1970 and 1990 (Sanchez-Sierra, 1994, p. 39). Coal use dropped while the use of less-polluting energy sources increased. Other energy sources are also being adopted. The continuous growth of hydroelectric power generation, solar water heating, solar photocells, and the use of biomass as an energy source are promising to the future of the region's economic and environmental stronghold. Energy efficiency, which is currently lower than the highest achievable, is also an important factor in the growth of the region. "As a function of the low levels of energy efficiency, there are short-term, low-investment savings potentials of as much as 11% and 10% of current oil and electricity consumption, respectively" (Sanchez-Sierra, 1994, p. 39). Although conservation efforts are being made, the energy consumption in these countries continues to slowly increase, as does the pollution that it generates (Energy and Environment, 1995, p. 43).

2.3 Energy use in Atlas Eléctrica

Energy has many purposes in a business. It is used for the production of the company's product and for general lighting and heating purposes (Chateau, 1982, p.138). The usage of power must be evaluated before a plan for conservation can be implemented.

Electrical utilities charge commercial customers based not only on the amount of energy used (kWh) but also on the peak demand (kW) for each month. Peak demand is very important to the utility so that it may properly size the required electrical service (Thumann and Metha, 1991, pp.109-110).

Energy and demand during peak usage periods are billed at much higher rates than consumption during other times. The difference in prices results from the utilities augmenting the power production of their large plant during periods of peak demand with small generators which are expensive to operate (Thumann and Metha, 1991, p.112).

2.4 Lighting

There are 4 major types of lighting that are used in commercial settings. These are incandescent lamps, fluorescent lamps, low-pressure sodium lamps, and high-intensity discharge lamps. Each type has its advantages as well as its drawbacks. In addition, some bulbs require ballasts (see Glossary) or special fixtures in order to work properly.

2.4.1 Incandescent Lamps

Incandescent lamps are the most common type of lighting in residential and office settings. These lamps are the least expensive to purchase but are the most expensive to operate. They have the shortest lives of the common types of lamps and are relatively inefficient. Some incandescent lamps turn as little as 6% of the energy used into light, with the remaining amount being turned into heat ("Light Shed on Lighting," Jan 8, 1998). There are three common types of incandescent lamps: standard, tungsten halogen, and reflector lamps.

Standard incandescent lamps, or the "A-type light bulb", are the most common yet most inefficient type of light bulb. They also have a short lifetime, and special "long-life" bulbs are more inefficient than the standard A-type bulbs.

Tungsten halogen lamps are more efficient than standard incandescent lamps but are considerably more expensive. These lamps have a gas filling and an inner coating that reflects heat. This allows for the heat to be recycled, therefore keeping the filaments hot using less electricity ("Energy Efficient Lighting," July 2, 1998).

Reflector lamps, or "type R", are a third type of incandescent bulbs. They are designated to spread light over specific areas. They are also used for floodlighting, spotlighting, and downlighting. There are two types of reflector lamps: parabolic aluminized reflectors, or type PAR, and ellipsoidal reflectors, or type ER. ERs are twice as energy efficient than PARs for recessed fixtures.

2.4.2 Fluorescent Lamps

Fluorescent lamps are alternatives to incandescent lamps. Fluorescent lamps last ten times longer than incandescent lamps and are three or four times as efficient. In order to achieve maximum efficiency, fluorescent lamps should only be installed in places where they will be on for several hours at a time. These bulbs also require ballasts. There are two basic types for fluorescent lamps: the compact fluorescent bulb and the tube fluorescent bulb.

The first type of fluorescent lamp is the compact fluorescent bulb. This bulb fits into the same sockets the incandescent bulbs. Although the compact fluorescent bulbs fit into the same sockets as the incandescent bulbs, they are heavier and larger. These differences may be problematic with desk and table lamps. These fluorescent bulbs typically replace incandescent bulbs that are three to four times their wattage and they last ten to fifteen times as long. They use seventy-five percent less electricity. However, they initially can cost ten to twenty times as much as the incandescent light bulbs ("Energy Efficient Lighting," July 2, 1998). Even with this initial extra cost, the fluorescent bulbs will pay for themselves after about 2500 hours of use and get about 12,000 hours of use.

Another type of fluorescent bulb is the tube fluorescent bulb. This light is used primarily for lighting large indoor areas. They create less direct glare than incandescent bulbs. The two most popular types are the forty-watt, four-foot lamps and the seventy-five-watt, eight foot lamps ("Energy Efficient Lighting," July 2, 1998). This type of fluorescent lighting is used predominantly in commercial indoor lighting systems.

2.4.3 Low-Pressure Sodium Lamps

Low-pressure sodium lamps are similar to fluorescent lamps in the way they work. They are the most efficient, maintain their light output better than any other lamp type, and have the longest service life of any artificial light source ("Energy Efficient Lighting," July 2, 1998). However, low-pressure sodium lamps are not very effective at color rendition, as it renders all colors as tones of yellow or gray. These bulbs are used primarily where color rendering is not important.

2.4.4 High-Intensity Discharge Lamps

High-intensity discharge lamps, or HIDs, provide the high lighting efficiency and long service life. However, the color rendition from these lights varies. Similar to fluorescent lamps, these lights require a ballast and use an electric arc to produce intense light. HIDs take a few seconds to turn on since the ballasts need time to establish the arc. HID lamps and fixtures can save 75-90% of lighting energy when they replace incandescent lamps and fixtures ("Energy Efficient Lighting," July 2, 1998). In general, these lamps are used for outdoor lighting applications. There are three types of HIDs: mercury-vapor lamps, metal halide lamps, and high-pressure sodium lamps.

Mercury-vapor lamps are the oldest type of HID lighting. These lamps provide 50 lumens per watt and casts a very cool blue/green white light. Mercury-vapor lamps are not very common, as they do not have good color rendition or efficiency.

Metal halide lamps have replaced many mercury-vapor lamps. These lamps are similar in construction and appearance to mercury-vapor lamps, with the only difference being the addition of metal halide gases into the bulb. This leads to higher light output, better color rendition, and more lumens per watt than mercury-vapor alone.

The third type of HID is high-pressure sodium lamps, or HPSLs. This type of lighting is becoming increasingly more popular. HPSLs provide 90-150 lumens per watt. Low-pressure sodium lamps are the only other light source that exceeds this efficiency. Like the low-pressure sodium lamps, HPSLs have long service lives and are very reliable. They produce a warm white color, and their color rendition ranges from poor to fairly good, depending on their design and intended use ("Energy Efficient Lighting," July 2, 1998).

2.4.5 Ballasts

There are two types of improved ballasts that can raise the efficiency of a fixture twelve to thirty percent. The first type is the electromagnetic ballast. This type operates at cooler temperatures, therefore, reduces ballast losses, fixture temperatures, and system wattage. The second type is the electronic ballast. This type operates at a very high frequency and is more efficient than the electromagnetic ballasts. These ballasts are generally lighter, turn on instantly, and are quiet ("Energy Efficient Lighting," July 2, 1998).

2.5 Conservation Methods

Energy conservation measures can be divided into two categories: general 'housekeeping' and energy-oriented changes (Sawhill and Cotton, 1986, p.71-72). Housekeeping strategies do not involve technical investments or production changes. These general strategies include turning off excess lights and machinery when they are not in use and using natural lighting as much as possible. The most basic approach to conserving energy is not running electrical machinery when the operator is not present. While this may seem basic, it is often overlooked when assessing of needs and problems of a company. The placement of windows and their composition are important when trying to minimize energy use. Not only will this provide natural light and therefore reducing a company's energy needs, but the actual composition of the window, glass and coating combinations, is important when deciding if installing windows is beneficial. See Table 2.1 for examples (Reay, 1977, p.112).

Table 2.1: Thermal Conductivity of Glass/Coating Combination

Type of window	Conductivity (kJ/m^2h °C)
Single glass	21
Double glass with air	11
Double glass with one coating	6.6
Double glass with one coating and krypton gas	3.8
Double glass with two coatings and krypton gas	3.3
Single glass with one coating	11

The conductivity of the windows indicates that amount of energy (or heat) that can pass through the window during a given period. The lower the conductivity indicates that less energy can be transferred through the window. This can help save energy since changing to a lower conductivity window will decrease the loss of heat (or coolness) and therefore require less energy to maintain the temperature in the building.

Another basic approach to save energy is to ensure that equipment is maintained and kept clean. Such opportunities include heating and cooling coils and lighting fixtures. A final housekeeping strategy for energy conservation is to close vents and ducts to prevent excessive air circulation and uncontrolled heating and cooling (Reay, 1977, p.112-113).

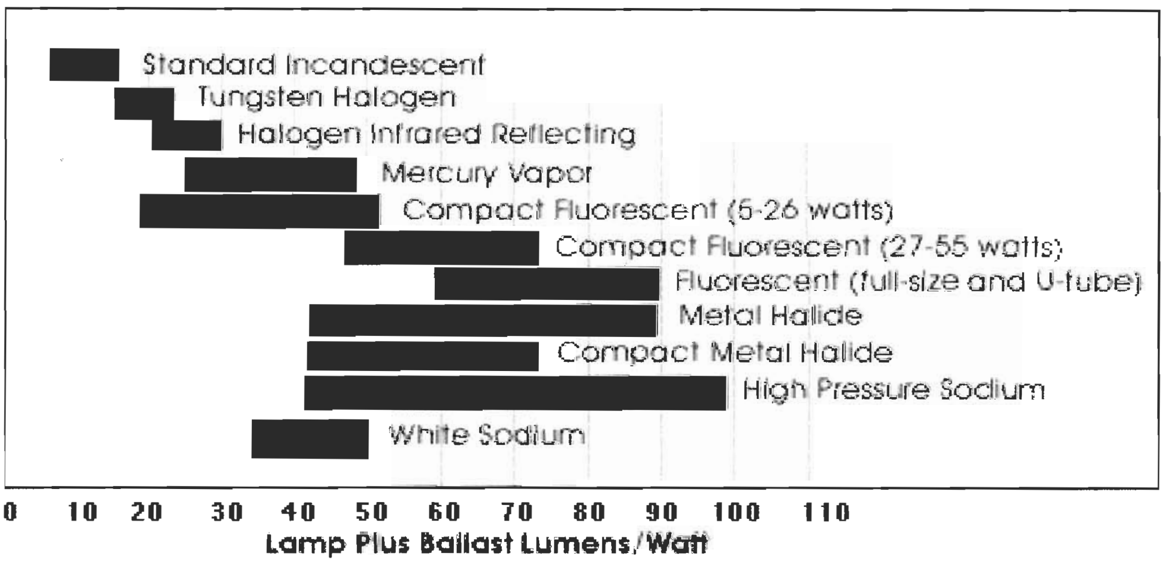
Energy-oriented changes involve the improvement of the production process and equipment upgrades. This type of change includes co-generation of energy and the upgrading of lighting systems, ventilation, air conditioning systems, windows and insulation. "By using energy-efficient techniques and practices, companies can reduce energy use by an average of 35%" (Dolin, 1997). For example, reset controllers and computer programs are available that can manage the air conditioner output so that the load is reduced during the night and over weekends. These units can pay for themselves in just a couple of months depending on what system is used (Reay, 1977, p.113).

2.5.1 Lighting

Lighting is another common area examined when trying to conserve energy. In the United States, for example, the Green Lights® part of the Energy Star® Buildings Program sponsored by the Environmental Protection Agency, EPA, predicts that "a typical business that upgrades its lighting can expect to reduce costs 25 to 45 cents per square foot" (Dolin, 1997). Upgrading lighting includes two aspects. First, the actual lighting system can be improved. Second, the type of lamps used can be replaced. There are four standard types of lighting systems: general/uniform, localized, local, and visual display units. General lighting provides a uniform illumination over the entire workplace. Localized lighting relates the positions of the lighting equipment to the areas that require high levels of light and the areas that require low levels. Local lighting illuminates only a small, discrete area directly around the area of activity. Visual display units, or VDUs, involve shining light off a screen to illuminate an area. VDU's, however, tend to lead toward bad vision and multiple reflections. Localized lighting is just as energy efficient as local lighting, but offers a better working environment, because there are not regions of relative darkness and lightness. A benefit of localized lighting is uplighting, which directs light from extremely efficient discharge lamps to the ceiling, producing a greater illumination than lighting directed towards a workstation (Roaf and Hancock, 1992, pp.73-74). This is only effective, however, if the ceilings are a light color, i.e. white, and are close to the lighting source.

Besides the lighting system, the choice of lamp is important. There are various alternatives to the standard white lamps and natural fluorescent bulbs. Pluslux and Polylux lamps are up to 70% more efficient than conventional cool white, white, and warm white bulbs (Roaf and Hancock, 1992, p.74). The Pluslux lamps contain argon and krypton as opposed to just argon and can pay for themselves at least three times over before they are used up. The Polylux lamps have a rare-earth phosphors coating and have a better color and light production than standard bulbs. Compact fluorescent lamps are also high on the energy efficiency list. These bulbs operate at a much safer temperature and their electric contacts cannot be touched together. Examples of these lamps include the 16W 2D lamp, which has the same light output as a 100W bulb and lasts 5 times longer, the 28W 2D lamp, with a light output equivalent to a 150W bulb and lasts ten times longer, and the 38W 2D lamp, which is equivalent to a 200W bulb and lasts ten times longer (Roaf and Hancock, 1992, p.74). Final examples of other energy efficient lamps include high-pressure sodium (50N) lamps and low-voltage tungsten halogen lamps. See Figure 2.1 for examples of lamp efficiencies ("SmarterEnergy, Lighting Systems Guide").

Figure 2.1: Relative Efficiencies of Lamp Sources



2.5.2 Lighting Controls

Lighting controls are devices used to turn lights on and off or for dimming lights. There are many types of controls. The simplest type is the standard snap switch. This allows people in large, shared spaces to turn off lights when they are not needed. Other types of controls include dimmers, timers, motion detectors, and photocells.

Dimmers can control the amount of light let off in an area. This can save energy since when less light is needed, less energy is used. Dimmers reduce the wattage and output of incandescent and fluorescent lamps. They also increase the service life of incandescent lamps, but reduce their lumen output more than their wattage. Fluorescent lamps require special dimming ballasts and lamp holders, but these does not reduce their efficiency ("Energy Efficient Lighting," 1999).

Timers are electric clocks that can be set to switch lights on and off on. There are two types of timers. The first type of clock automatically turns lights on or off for security, safety, and tasks at specific times of the day. The second type is the crank timer. These timers are spring driven and resemble a traditional oven timer. They are manually turned on and set by a person when they enter an area and go off after the specified amount of time.

Motion detectors, or occupancy sensors, detect movement in a target area and automatically turn lights on for a preset time. After the preset set, the lights turn off if there is no further movement.

Photosensors, or photocells, work by sensing the amount of natural light at a given time. If the light level drops below the given value, the photosensor will turn on the lights in that area. Once the light level returns to the acceptable value, the lights are then turned off. Advanced photosensors can gradually raise and lower the fluorescent light levels in response to the changing daylight levels ("Energy Efficient Lighting," July 2, 1998), thus allowing for the total amount of light to remain constant.

2.5.3 Window Material

One of the considerations in selecting windows is the amount of glare. There are three types of glare: direct glare, reflective glare, and veiling reflections. Direct glare is light shining directly into a person's eyes. Reflective glare is the reflected light shining into a person's eyes. Veiling reflections is a type of reflective glare that is light reflected off a work surface. This type of glare can obscure contrasts and reduce clarity of the tasks ("Energy Efficient Lighting," July 2, 1998).

2.5.4 Skylights

Using skylights is another way to reduce the electrical consumption of a company. While skylights may cut down on the amount of electricity that needs to be spent on lighting, there are many aspects of the skylights that need to be considered before they are installed.

The first consideration is the amount of light that the skylight allows into the building. The material that the skylight is made out of needs to be translucent enough to allow enough light in for the workers. The three main types of skylight material are polycarbonate, glass, and acrylic. These three materials allow similar amounts of visible light through them, but have different strengths. The polycarbonate is the strongest of these materials and glass is the weakest ("Alpenglass/Heat Mirror™ vs. 'Low-e' Glass: The Myths and the Facts," 1998).

Another consideration is the amount of heat that is let in by the skylight. One of the ways to minimize the heat let in is to apply a "low-e" coating to the skylights. The low-e coating is a suspended film on skylights and windows that reflects heat and transmits light. There are two main categories of low-e coatings. The first is the sputtered or soft-coated. This coating is high-performance and must be sealed in an insulating glass unit. The second is the pyrolitic or hard-coat. While this coating does not need to be sealed onto a glass unit, it is generally less effective. It is mainly used for winter insulation and is not as efficient for keeping out heat in the summer. Although low-e coatings are used to block heat entrance, they must be combined with tinted or reflective glass to be effective. Most low-e coatings also give the glass a colored tint ("Alpenglass/Heat Mirror™ vs. 'Low-e' Glass: The Myths and the Facts," 1998).

2.5.5 Equipment Variation

When possible, machinery should be run at variable speeds. If machinery is run at one speed all day, there are times when energy is wasted. However, the running of machines on variable speeds wastes less power at times during the day when the machines are not in use (Long, 1989, p.165).

Another way to minimize the cost is to use higher voltage distribution design equipment. This type of design may lead to the elimination of excess primary transformers (Zackrison, 1984, p.9). It is often more economical to supply power at a constant current as opposed to a constant potential (Smith, 1979, p.81). The power factor (see Glossary) improves with the rise in horsepower in a motor. Although a motor with a high horsepower generally has a better power factor than one with lower horsepower, the power factor varies with the type and quality of the motor (Smith, 1979, p.80). All the electrical equipment ideally should be at the highest specified power factor, causing it to consume less kVAR than equipment run at a lower power factor (Zackrison, 1984, p.25-26).

The wiring of the building should also be examined when trying to conserve energy. While there are many different plans for wiring a building, branch circuit wiring is often very economical. When branch circuit wiring is used, it minimizes the length of conductors and conduit wires (Zackrison, 1984, p.12).

The primary transformers that are used in the company should be liquid rather than dry (Zackrison, 1984, p.9). Liquid transformers are more efficient and last longer. Many of the older liquid primary transformers were made with pentachlorobiphenyl, PCB, as a cooling agent. Since PCB's have been declared a toxic substance, the primary transformers are now being made with a less flammable silicone liquid (Zackrison, 1984, p.10).

Energy Management Systems (EMS), a digital technology, proposes to decrease the energy costs and increase energy awareness (Thumann and Metha, 1991, p.106). A company trying to decrease their energy consumption uses it as a guide. Although this software provides a good outlook and advice for the company, it is very expensive.

2.6 Benefits

2.6.1 Environmental

Energy planning and conservation in industry are important to current running costs, but also to future costs and the environment. The major reasons for explicit planning are:

- the continuing desire to maintain profitability when facing increasing energy costs
- the urgent desire to maintain adequate and stable energy supply for undisturbed production schedules

- the need to manage large capital required for conservation technology that possess substantial conservation potential
- the requirement to comply with government's energy conservation or efficiency standards
- the need to present to consumers an image of energy efficiency

(Hu, 1983, p. 56).

2.6.2 Economic

Many times companies do not think about conservation until their profit margin decreases significantly. One way that many companies try to increase their profit is to decrease their spending. Conservation of energy saves the company money and, therefore, is often looked toward as a solution (Long, 1989, p.152). When a company decides to conserve energy, spending on a fixed source of energy is cut. Money spent on a fixed source of energy is money spent on heating, cooling, lighting, and operating machinery. When a company starts to conserve energy, the amount of money spent is smaller, and the company saves money (Long, 1989, p.156).

Financially, energy conservation directly relates to running cost, or money per kWh used. Overall, most industrial plants have a power factor between 70-95% (Elliott, 1989). However, future economic problems can develop if electrical equipment is subjected to abnormal voltages since this leads to the deterioration of electrical insulation. "The factors governing this deterioration mechanism include the type of dielectric material and its physical properties, overvoltage exposure (magnitude, wave shape, duration, repetition rate, cumulative duration), ambient conditions (temperature, humidity, moisture, dust, ions), and operating conditions" (Prabhakara et al., 1996, p. 10.1).

In developed countries, pollution of the environment also drains a company financially as clean-up costs can be substantially higher than preventative costs. In developing countries, this is not as rigorously monitored since "developed and developing countries have divergent notions of equity in energy use and environmental responsibility" (Energy and Environment, 1995). Without monitoring, the immediate cost is less because the companies are not made to clean up their mess. Although, in the future, new regulations could be imposed which would make the cleanup necessary. It would be extremely costly for businesses to implement this cleanup.

2.6.3 Equipment

The conservation of energy adds life to the equipment and machinery that a company is using. Not only is there less wear and tear, but lower energy levels prevent surges and overvoltages, which can not only damage sensitive machinery, but can also harm computers. Based on this, voltage/circuit levels based on load size need to be monitored and are listed in Table 2.2 below (Prabhakara et al., 1996, p.2.10).

Table 2.2: Voltage/Short-Circuit Level Selection Based on Load Size

Volts	Transformer Rating, MVA	Transformer Load, MVA	S.C. Interlevel KA	mVA	Transformer full load Amperes	S.C.R. load*	Max. Motor Size
480	1.0	0.8	22	18.3	1,203	23	200
	1.5	1.2	33	27.5	1,804	23	300
	2.0	1.6	44	36.6	2,406	23	400
	2.5	2.0	55	45.8	3,007	23	500
2,400	7.5	6.0		150	1,804	25	2,000
4,160	15	12		250	2,082	21	3,000
13,800	30	24		500	1,255	21	5,000
	40	32		750	1,673	23	7,500
	50	40		1,000	2,092	25	10,000

*measure of the critical recovery voltage

2.7 Alternative Sources of Power

2.7.1 Solar

An attractive energy source is the sun. Because it is free, clean, and non-polluting, people often view it as a readily available source. Using solar energy for power does not involve the use of dwindling, finite resources (Corbitt, 1993, p.200). Although the actual cost of the resource is free, the equipment to harness the power from the sun can be expensive and a large investment for a company.

2.7.2 Hydroelectric

Turbines located in barrages, or artificial dams, pump water into an estuary. When the tide rises, the salt water and fresh water combine in the estuary. When a sufficient amount of water is built up in the estuary, the water flows back through the turbines to produce electricity (Corbitt, 1993, p.200). Ocean power may also become an energy source in the future which can be used by either its wave power or as ocean temperature differential (Corbitt, 1993, p.201). While water provides a great source of energy, it is imperative that the buildings using the waterpower be near a large river or ocean for the water to provide the desired effect.

2.7.3 Geothermal

Geothermal energy is based on the fact that the earth's core is hotter than the surface. The steam trapped in the earth, when brought to the surface, drives turbines to produce electricity. Alternatively, water can be heated by pumping it through deep hot rocks. Although theoretically limitless, in most inhabitable parts of the world, this energy source is so deep that drilling hole to reach it is very expensive (Corbitt, 1993, 201).

2.7.4 Wind

Wind can generate electrical or mechanical energy. Rotating devices known as windmills can convert the mechanical energy of wind to electricity (Corbitt, 1993, p.200). These work very well in places with strong wind, but in milder, less windy climates the amount of electricity produced is not enough to run a factory.

2.8 Conclusion

While there are many new ideas for reducing energy consumption through alternative energy sources, organizations often prefer to continue using methods they know. Many businesses choose to stay with electricity because it is safe and secure to them (Chateau, 1982, p.155). While other sources may be economical in the end, they often require an initial investment. This is an investment of both money and faith that the new systems will work as well as electricity. However, "by using energy-efficient techniques and practices, companies can reduce energy use by an average of 35%" (Dolin, 1997). The final results ultimately depend on the attitude and financial resources of the company (Chateau, 1982, p.152).

Chapter III

Methodology

Chapter III.

Methodology

3.1 Objectives

In this project, we had two main objectives. Our first objective was to reduce electrical consumption of Atlas Eléctrica. Specifically, we make recommendations on how to reduce the electricity usage from lighting the factory. Our other objective was to redesign the lighting structure of Atlas Eléctrica. By redesigning the structure, we provide a plan for enhancing the quality of lighting at the workstations.

We chose to focus on the lighting of the factory for three reasons. First, lighting was an easily measurable form of electricity usage. We had access to the lighting control switches and it was simple to tell when the light was in use. Second, the lighting system has a direct impact on the quality of the working environment. Having adequate light helps the productivity of a factory and increases worker satisfaction. Finally, the design of a new lighting system was needed if Atlas plans to expand its plant.

Our measurements had some limitations. First, with the light usage count, we had a limited amount of time that we were in the factory. Since time was short, we were not able to make a complete count of all the lights in the factory, offices, and exterior. We concentrated on the lights that were used in the production of the refrigerators and ranges. Therefore, the areas that we looked at were the lights over the assembly line and the lights over the aisles. However, we were unable to record light usage for the warehouses or the offices. We chose to concentrate on the factory since this is where most of the lights are used.

3.2 Introduction to Atlas Eléctrica

Our first day at Atlas, Pablo Solís, from the Facility and Machinery Maintenance department, gave us a general tour of the factory. He took us around the factory and described the basic process of making a refrigerator. He explained what parts of the refrigerators the different machines made.

The next day, Julio Zúñiga, Project Engineer, gave us another tour of the factory. He also showed us the different machines and what each part of the process did. He also pointed out the areas that he thought were the most problematic in the lighting structure. He introduced us to the people in his department and some of the management in the company. These introductions allowed us to approach any of these people to ask for help and information when it was needed.

3.3 Interviews

Due to the language barrier between our group and the workers at Atlas, we chose to gather our information through informal interviews. We were only able to talk with the management since the factory workers spoke little or no English and our team spoke very little Spanish. Although the management did speak some English, we chose an informal format for our interviews because it allowed for easier communications.

We had an interview with Srs. Solís and Zúñiga to discuss the lighting of the plant. We talked about the lighting in the plant and the possible direction of our project. Srs. Solís and Zúñiga advised us to look into lighting alternatives. They wanted us to evaluate Atlas' current lighting structure, taking into consideration the layout of the lights and the possibility of using more natural light. Another issue to consider was the amount of heat that enters the factory through windows and skylights. Srs. Zúñiga and Solís gave us the basic information on the set up of the plant and the different processes. We discovered that the management of the plant was concerned about the lighting in the factory. We also learned that Atlas plans to expand in the next couple of years. When they grow, Atlas wanted to create the best work environment for their employees. In order to provide the best working environment, Atlas needed to provide optimal lighting for the workstations and the aisles. Srs. Zúñiga and Solís conveyed to us their concern for the lighting problem. They wanted us to not only tell them what the ideal lighting was for the factory, but they also wanted us to investigate different types of lighting systems and structures.

In order to obtain information about lighting, we also spoke with an outside source. Through our contacts in Baxter Healthcare International, we met with Julio Aguilar, Facilities Engineer. He is in charge of the lighting throughout Baxter. Our interview with him allowed us to gather general information about lighting in factories. He also provided us with a description of what Baxter did to improve their lighting and lower their electricity usage.

3.4 Data

First, we made a rough count of the lights in the factory. We counted both the fluorescent and the sodium bulbs that were in the factory. With the fluorescent bulbs, we counted each lamp with two seventy-five Watt bulbs in it as one light. Each individual sodium lamp was counted as one light. We also noted their relative location in the factory. From this information, we drew rough floor plans of the lighting structure of the factory. We divided the plant into sections and made plans for each of these, as well as a comprehensive floor plan. The sections that we made were used in both our light counts and in our light readings.

Using our floor plans, we determined the lights that were used during the day. We counted the number of lights that were turned on in each of the sections at various times of the day. We divided the day into four sections. These sections included morning, midday, afternoon, and evening. We chose these times of the day since they represented the different amounts of natural light that was present in the factory. Our first sample was taken at about ten in the morning. This allowed us to count how many lights were on when the maximum amount of natural light was entering the building. To make sure that we had accurate and reproducible results we repeated these measurements on two other days. We repeated the count around noon on a different day. This provided us with information about whether lights were left on while the workers went to lunch and took their breaks. We also wanted to see if they used more lights in the afternoon when it was cloudy and raining. We observed the light usage between three and four. Finally, we wanted to see if there were more lights turned on after it became dark. Therefore, we recorded the light usage in the evening, after five p.m., to determine what the usage in that time period was.

Next, we met with Edwin Cardoza in the Maintenance Department to determine which light bulbs were controlled by which switches. He showed us around the factory and allowed us to turn on and off all the light switches. We made a record of what lights were controlled by which switches. There were several switches that did not appear to turn on any lights, and some lights did not appear to be controlled by any of the switches. These observations were probably due to burned out bulbs.

We also took light measurements throughout the factory. We used a light meter to measure the brightness at the workstations and determine if there was adequate light for the task to be preformed. The light meter that we used was a GE Model 216 Triple Range light meter. Depending on the task, different amounts of light are needed. We measured the light in each section of the factory. We chose a point in each section that appeared to have the average amount of light in that section. This point was marked on our floor plans so we could take the light reading from the same spot every time. We preformed these measurements both during the day when Atlas could optimize both natural and artificial light and during the evening when Atlas had to rely on artificial lighting. We wanted to benchmark the different areas of the factory against each other to determine the places where the lighting was adequate.

3.5 Research

Besides gathering data from the factory, we performed research on various aspects of our project. However, the research material we obtained was limited as we were forced to do most of the research over the Internet. Although there is a lot of information on the Internet, we needed to be careful of our sources as many of the sites we looked at were either commercial or advertisements. We had difficulty using the information in the libraries in Costa Rica for two reasons. First, most of the books and journals were in Spanish. Since none of us spoke fluent Spanish, translating the material was nearly impossible and took many hours to obtain a small amount of information. Second, most of the resources were out of date.

We researched different types of light bulbs. While looking at the various types of light bulbs, we were concerned with the illumination, life span, and electrical usage of each. We needed to find lights that would maximize the light output while reducing the amount of electricity used.

Besides different types of light bulbs, we also looked into different materials for windows and skylights. Our goal was to find the best material that would allow the most light to enter while limiting the heat buildup in the factory. We investigated different types of coatings that could be applied to present and future windows to reduce the amount of heat entrance.

In addition to using online sources, we also used the Grainger CD catalog. We used this catalog to compare the price of different bulbs. We were able to gather comparative data about which bulbs would be economical to replace.

Another catalog that we used was the Thomas Register of American Manufacturing. From this catalog, we gathered information on various light meters as well as light bulbs and ballasts.

Chapter IV

Results and Analysis

Chapter IV.

Results and Analysis

4.1 Interviews

The interviews that we conducted helped us to determine the focus of our project and to obtain the information we needed. Refer to Chapter III: Methodology for a description of how we chose our interviewees and the determined format of the interviews.

In our interview with Julio Aguilar, Baxter's Facilities Engineer, we discussed possible ways to improve lighting. We addressed different types of bulbs and the steps that Baxter had taken to improve their lighting. When talking about the different types of bulbs, Sr. Aguilar gave us both the benefits and the drawbacks to each bulb. He informed us that while incandescent bulbs were cheap to buy and install, they had to be replaced often and they were less efficient than other types of bulbs. He also told us that although fluorescent bulbs were more expensive they were more efficient and lasted longer than incandescent bulbs. He felt that sodium bulbs were not good bulbs to use. He stated that the lights took a few minutes to warm up and could not be placed on timers or any other energy saving devices. After this brief discussion on bulbs, he told us about Baxter's Efficient Illumination project. This project was completed by Baxter in 1997 to increase the light quality of the factory while saving energy. Since they only used incandescent lights outside the plant, they were able to replace all of the incandescent bulbs with sodium bulbs. These exterior lights were used for general security lighting and were also used as bug lights. Since they had these dual purposes, they were left on the entire night and the amount of time that they took to warm up and turn on was irrelevant. Baxter also replaced their fluorescent bulbs. They went from having a light with two ballasts and four bulbs to a light that had one ballast and only two bulbs. These new lights also had a diffuser that was prismatic and an aluminum reflector. These two devices increased the amount of light given off by the bulbs. Through these changes, Baxter saved over 645,000 kWh in the next year in energy costs.

4.2 Data

We obtained three major sets of data in the Atlas factory. First, we performed a light count. This informed us as to how many lights were in the factory and where they were located. We also did a similar count of the number and placement of skylights in the building. Finally, we made light intensity measurements throughout the factory to determine how much light the skylights and artificial lights provided.

4.2.1 Light Count

Through our light count, we recorded the average number of lights that were on in the different sections. We were able to perform these counts at different times of the day. Although the number of lights on is not directly related to energy conservation, determining if excess lights are on when they do not need to be is important when trying to cut back on energy usage. See Table 4.1 for a summary of how many bulbs were on at different times of the day and Appendix C for in-depth charts showing the light usage in each section.

Table 4.1: Light Usage - Summary

	% fluorescent bulbs on	% sodium bulbs on	% total bulbs on
Morning (9-11)	53.0%	4.50%	49.8%
Midday (12-2)	52.6%	3.60%	49.4%
Afternoon (3-4)	60.7%	12.6%	57.6%
Evening (5-6)	67.9%	19.2%	64.8%

Table 4.1 shows the percentage of lights turned on at the given time periods. As the table indicates, the amount of light usage (both fluorescent and sodium) increased throughout the day. The morning and midday readings were very similar, where as the afternoon readings were higher than the earlier two and the evening readings were the highest. This increase was expected since as the day goes on, there was less natural light and, therefore, more artificial light was needed. In the mornings and at midday, the amounts of natural light in the factory were nearly the same, which was indicated by the number of lights turned on. The morning actually had more lights on than did midday, which was surprising since there was more natural light at that time. However, this can be explained since many of the workers went to lunch between 12:00 and 1:00 in the afternoon. Another explanation is that there was a shift change at around 1:30. During this time, many of the processes were stopped for a short time period and, therefore, higher levels of light were not needed. In the afternoon, more lights were in use since it was starting to get dark out. This darkness was due to the weather conditions in Costa Rica. Clouds and rain are frequent this time of year in the afternoon, leading to less natural light entering the factory and a darker workplace. Thus, more of the artificial lights needed to be turned on. In the evenings, the amount of natural light had decreased even more due to the sun setting. It was expected that this time period would require the most artificial light in order to maintain a suitable working environment in the factory.

However, some sections in the factory have almost no artificial light during the evening since there are no workers in those areas. For example, Metal Mechanic 1 averaged 11 out of 25 fluorescent bulbs on during the midday time period, but only 8 out of 25 fluorescent bulbs on during the evening. On the other extreme, Metal Mechanic 3 averaged 9 out of 41 fluorescent bulbs on during the morning but 35 out of the 41 in the evening.

4.2.2 Skylight Count

In addition to our light count, we also took an inventory of the placement of the existing skylights. This allowed us to compare the location of the fluorescent and sodium bulbs to the location of the skylights and determine if they were adequately spaced. This also allowed us to determine which areas would be most beneficial for the addition of new skylights. We recorded both the placement and the numbers of skylights in each section. Table 4.2 shows the number of skylights in each section, as well as the numbers of fluorescent and sodium bulbs present in each section. For information about the placement of the light bulbs and skylights within each section, refer to the AutoCAD drawings in Appendix F. By consolidating the artificial light and skylight data, the areas in the factory that only had good artificial lighting, only good natural lighting, both, or neither were discovered.

Table 4.2: Lighting Count

Section	# of fluorescent bulbs	# of sodium bulbs	# of skylights
Metal Mechanic 1	25	26	55
Metal Mechanic 2	78	3	69
Metal Mechanic 3	41	0	56
Painting	24	0	0
Outside Painting	12	0	2
Assembly Line 1	26	0	3
Corner Section-fridge	82	1	6
Assembly Line 2	40	2	7
Stove Oven	44	0	4
Center Bottom Floor	23	4	3
Middle Back Section-Fridge	42	0	6
Testing Area	38	0	11
Section 1525	7	0	0
Stove Assembly	46	0	10
Packaging	9	1	2

4.2.3 Light Meter Readings

The time that we were able to use the light meter was limited. Since Atlas did not own a light meter, we had to borrow one from Sylvania, a light manufacturing company. Because it was a borrowed meter, it was only available to us for a few days. We had to take the measurements on the days the meter was at Atlas. Using the light meter, we were able to record the light values for the different areas of the factory. We measured the light in the different parts of the factory at the same times of day as we counted the light usage. We also used the same sections for our observations. This enabled us to compare the light meter readings and the number of lights that were on during that time. See Table 4.3 for a summary of the light meter readings, measured in Lux (see glossary), and Appendix D for the complete results. The optimal light reading for workstations is between 2000-5000 Lux ("Energy Efficient Lighting," 1998). As shown in Table 4.3 this amount of light was rarely achieved in the factory. Although this reading is optimal for workstations, it is more light than is needed for aisles and over conveyor belts. For these areas of the factory a light reading of 300-500 Lux is sufficient ("Energy Efficient Lighting," 1998).

Table 4.3: Average Light Meter Readings (Lux)

Section	Morning	Midday	Afternoon	Evening
Metal Mechanic 1	1666.7	906.7	250.0	76.7
Metal Mechanic 2	1086.7	350.0	180.0	153.3
Metal Mechanic 3	2066.7	2293.3	613.3	573.3
Painting	85.0	80.0	190.0	60.0
Outside Painting	363.3	353.3	390.0	391.7
Assembly Line 1	320.0	280.0	290.0	283.3
Corner Section-fridge	360.0	260.0	120.0	73.3
Assembly Line 2	890.0	1253.3	163.3	73.3
Stove Oven	56.7	60.0	48.3	46.7
Center Bottom Floor	51.7	50.0	40.0	43.3
Middle Back Section-Fridge	240.0	216.7	123.3	83.3
Testing Area	1133.3	646.7	240.0	103.3
Section 1525	243.3	206.7	195.0	203.3
Stove Assembly	213.3	170.0	93.3	60.0
Packaging	1296.7	1733.3	603.3	28.3

To compare the light readings with the percentage of lights on and number of skylights present, see Appendix E. These comparisons were performed during the four established time periods and relied on the average values for the light readings and percentage of lights on during those times.

4.2.4 Light Controls

With the help of Edwin Cardoza, we found the light controls for the factory. We spent an afternoon walking around the factory turning on and off all the light switches. We went to all the control panels and tried all of the switches. Through all of the trials, we learned where most of the controls to the lights were. Most of the switches were not labeled at all, and those that were labeled were often labeled incorrectly or only partially correct. We also found that many of the switches did not appear to control any of the lights. However, many lights did not turn at all during our trials. Overall, 166 of the 537 fluorescent bulbs, or 30.9 percent, did not appear to be controlled by any of the switches. Similarly, 3 of the 37 sodium bulbs, or 8.1 percent, were not turned on during our light control search. Since there seemed to be more switches that controlled nothing than lights that didn't turn on, we concluded that many of the lights that did not turn on were burned out and that some were controlled by the unknown switches. The rest of the switches probably controlled office lights and electrical outlets.

4.3 Research

When we looked into different lights, we found that there are many types of bulbs. We wanted bulbs that would provide crisp clear light, but would also be energy efficient and low in cost. We researched three main types of light bulbs. They were the incandescent, the fluorescent, and the sodium bulbs. From our research on the Internet, the Grainger CD Catalog, and the Thomas Register of American Manufacturing, we found different information for the various types of light bulbs. We discovered some facts about their light output and energy use. We also learned about the cost of the different types of bulbs. See table 4.4 for a comparison of incandescent and fluorescent bulbs ("Compact Fluorescent Lightbulbs," August 19, 1996).

Table 4.4: Incandescent and Fluorescent Bulb Comparison

	Incandescent	Fluorescent
Bulb Model	General Electric 75 watt	Lights of America #2022
Brightness	1300 lumens	1550 lumens
Color Quality	91%	86%
Power	75 watts	22 watts
Market Price	$1	$20
Lifespan	1,000 Hours	12,000 Hours
Hum	No	No
Flicker	No	No
Instant-on	Instant	Instant

The incandescent bulb is the cheapest bulb to initially purchase. While costing less to purchase, they burn out relatively quickly. They need to be constantly monitored and replaced, making them ultimately a costly bulb.

In the majority of the factory, the bulb that is used is the fluorescent bulb. These bulbs often require a rather large initial investment. While they cost more than incandescent bulbs, they last 10-15 times longer and use less energy to produce the same amount of light. The fluorescent bulb seemed like the most logical choice for a factory. Fluorescent bulbs last a relatively long time and, when installed with electronic ballasts and reflective material, can provide excellent light while using minimal electricity. Although the bulb uses less energy, it is expensive. The cost of an individual bulb is about twenty dollars. Although twenty dollars is rather large amount to spend on a bulb, when used with reflectors, the bulb can provide the same quality and amount of light as an incandescent bulb. Since fluorescent bulbs are also more efficient than incandescent bulbs, money is saved. After 2,500 hours of use, the fluorescent bulb pays for itself. Another energy saving feature about fluorescent bulbs is that they could be placed on other energy saving devices. A fluorescent bulb can be controlled by both photo and motion sensors. This feature enables the bulbs to be paired with these sensors, and thus located in areas that need to be lit for short periods during the night.

Finally, sodium bulbs are used in the factory as a supplemental light source. These bulbs are energy efficient, but they are often impractical to use. Although sodium bulbs use less energy than incandescent bulbs, replacement of the incandescent bulbs by sodium bulbs was not often considered. The first reason sodium bulbs were not chosen to replace the incandescent bulbs is that there is a time delay when the sodium bulbs are turned on. This delay makes it impossible for sodium bulbs to be used with motion sensors. Since motion detectors are used to turn on lights as soon as movement was detected, the use of sodium bulbs would defeat this purpose. The other drawback to the sodium bulb is the quality of light that this bulb provides. Most of the sodium bulbs produce a light with a strong yellow or gray tone. This color is undesirable in a working environment, usually only used for security and outdoor paths. Table 4.5 illustrates the primary industrial uses for the different types of bulbs ("SmarterEnergy, Lighting Systems Guide").

Table 4.5: Industrial Lighting Uses

End Use	Incandescent	Fluorescent	HID (HPS or MH)
Outdoor Safety & Security; Exit Signs	No widespread applications	CFL and FL for walkways, and other relatively small areas. Above 32F.	Excellent for large areas allowing high fixture placement. Low wattage for walkways and entrances.
High Bay Assembly/Process Areas	No widespread applications	Some application for high output and super high output FL. Mounting height up to 16 feet.	Excellent applications. MH for color critical, else HPS. Mounting height 20 to 50 feet.
Low Bay Assembly/Process Areas	No widespread applications.	Excellent for FL. Mounting height 8 to 16 feet. Useful for task lighting.	Excellent applications for low brightness HPS, MH fixtures. Mounting height 12 to 25 feet.
Design and drafting Areas	No widespread applications.	Excellent applications for FL.	Limited applications for indirect MH lighting.
Warehousing and Storage Areas	No widespread applications.	CFL and FL for storage areas. Align F40 or F96 with aisles for effective lighting.	Excellent for storage areas, with ceilings over 14 feet. Special aisle lighting fixtures used for narrow tables
INC = Incandescent **FL** = Fluorescent **CFL** = Compact Fluorescent **HPS** = High Pressure Sodium **MH** = Metal Halide			

Through our research, we also obtained valuable information about skylights. First, the type of material used for the skylight is important. The three major materials used for skylights (polycarbonate, glass, and acrylic) allow similar amounts of light in, so the deciding factors in choosing a material are strength and cost. The strongest material is the polycarbonate while the weakest is glass. Polycarbonate is 250 times stronger than glass and 30 times as strong as acrylic sheet ("Glazing Grade High-Performance

Polycarbonate Sheet"). Likewise, the cost of the materials differ. For example, a 16mm, tri-wall polycarbonate skylight costs between $3.60 and $4.35 per square foot depending on the tint of the skylight. However, a 2-wall tempered glass skylight costs between $5.00 and $10.00 per square foot ("Sundance Supply"). Finally, high-impact acrylic skylights costs around $3.00 per square foot. Depending on the environment that the building is in and the financial status of the company, the choice of material varies. Next, the thermal conductivity of the skylight is important. "Low-e" coatings reflect heat while still transmitting light. Out of the two main categories of low-e coatings, the sputtered coating appears more beneficial to Atlas Eléctrica since it is more efficient at keeping out the summer heat than the pyrolitic coating. Some low-e coatings, such as the Plexiglas EX Heatstop 4029, can cut the heat buildup due to solar energy in half ("A&S Skydomes in Heatstop," April 1, 1999). The third important consideration with skylights is location. In general, skylights should be positioned on the east and south sides of a building since the sun is not as strong when it rises than when it sets. This positioning allows for less heat build-up while still permitting light to enter. Atlas' factory, though, is not set up in a manner so that this minimal heat buildup arrangement could be achieved. Therefore, the location of the skylights is not as important as the skylight material or coating.

Chapter V

Conclusions and Recommendations

Chapter V.

Conclusions and Recommendations

5.1 Energy Reduction

Our first objective was to reduce the electric consumption at Atlas from lighting the factory. In order to do this, we evaluated the present lighting in the factory. From this information, we were able to compare the lighting in the different parts of the factory. We compared the light reading that we measured with the light meter to the optimal light reading for a workstation. We found that most workstations needed more light, while the aisles often had excess light. The sections that had adequate light used natural light. These sections usually had the fluorescent lights turned on even when there was sunlight. In order to save both energy and money, the lights should not be turned on when the sun provides enough light for the task. By connecting the lights to photosensors, the lights will only come on when there is not enough natural light in the workstations. These sensors allow the workers to have adequate lighting throughout the day without having to control the lighting themselves. The photosensors can be programmed to respond to different levels of light. These settings enable the workstations to have the necessary lighting without using excess lighting over the aisles.

While the photosensors should be used to control the lighting at the workstations, motion sensors will be more beneficial in the areas of the factory that are used infrequently when it is dark. These sensors allow these areas to be lit when people are working in them, but not when there is no activity. These sensors prevent lights from being left on in these areas and thus reduce the energy spent. See Table 5.1 for the cost and energy saving potential for common light controls ("SmarterEnergy, Lighting Systems Guide").

Table 5.1: Typical Lighting Controls

Control Type	Cost (w/o installation)	Typical Energy Savings
Timers	$15-$30	Varies
Photosensors: Dimming	$50	30-40%
Occupancy Sensors		
(wall-mounted)	$30-$90	35-45%
(ceiling-mounted)	$50-$100	35-45%

Another way to reduce the electrical consumption is to change the light bulbs that are used in the factory. In the factory, the bulbs that are used are T12 fluorescent bulbs with two electromagnetic ballasts. These bulbs are 75 Watts each. When new lights are added to the factory, they should be T8 fluorescent bulbs. These bulbs are 60 Watts and they can use a single electronic ballast. When used with reflective material, the T8 bulbs produce the same amount of light as the T12 bulbs but they use 30 fewer Watts, or a 20 percent savings. If the T8 bulbs are placed on a single electronic ballast as opposed to the double electromagnetic one, they will save additional energy. See tables 5.2-5.4 for cost analysis of replacing the present T12 bulbs with T8 bulbs.

Table 5.2: Annual Bulb Usage

Average # bulbs on:	314
hours/day:	15
days/year:	280
total 'bulb' hours/year:	1,318,800

Table 5.3: Bulb Savings

	T12	T8
Bulb hours/year:	1,318,800	1,318,800
Watts/bulb	150	120
kWh/year	197,820	158,256
kWh saved/year	39,564	
Colones/ kWh	8.89	
Savings/year	¢351,723.96	
Savings (US$)/year	$1,234.12	

Table 5.4: Return of Investment*

Approximate cost of bulb	$40
Number of bulbs	537
Total costs for bulbs	$21,480
Savings/year	$1,234.12
RI	**17.4 years**

* figures do not include price of new ballasts or installation costs

With the return rate being 17.4 years, it would be impractical for Atlas to replace all of their current T12 fluorescent bulbs with T8 bulbs. However, replacing the bulbs in areas where the lights are always on, for example in Section 1525 and the testing area, would be beneficial. Atlas could also save energy and money by installing the T8 bulbs instead of the T12 bulbs when they expand their factory. The T8 bulbs would save them 20 percent of their lighting costs over using the T12 bulbs.

Finally, the control panels for the lights need to be reevaluated. The system that Atlas has for the lights at the present time does not identify which lights are controlled by which switch. In order to more efficiently use the lights in the factory the control panels need to be labeled. Each switch needs to be identified with which section of lights it controls. This labeling prevents unnecessary lights from being left on because the workers do not know which switch turns them off. To label the light switches, a careful inventory has to be taken. First, this inventory should be done when no one is working in the factory and all of the lights are off. The best time to do this is in the morning or afternoon while there is enough natural light to see around the factory. Next, all of the control boxes need to be given a number. This numbering provides an easy way to reference the different boxes. Once all the boxes are labeled, the switches can be labeled. This is a tedious and time-consuming task. All of the switches in every box need to be turned on individually. While the switches are turned on, the lights and machinery that they control need to be recorded. After all the switches are identified, labels should be made that concisely indicate the function of each switch.

5.2 Lighting Structure

Our other objective was to redesign the lighting structure of Atlas to enhance the quality of lighting at the workstations. We evaluated different types of bulbs to find the most economical and efficient. From this data, we found that using fluorescent bulbs is the best way to light the factory. Fluorescent bulbs not only are efficient, but can also be connected to motion sensors and photosensors. When placed on the sensors, the lights automatically turn on when needed without using excessive energy, as described previously. These lights should be placed in the same direction. There should be even spacing between bulbs and between rows of bulbs. The rows of bulbs should be parallel to the direction that workstations are set up. This pattern increases the amount of available light to a station without having unnecessary lights.

Another thing to consider when adding additional workstations is the number of skylights. These should be placed on the south and east side of the building, if possible. This placement allows for the maximum amount of light to enter while keeping the most heat out. The skylights should also be spaced evenly throughout the roof over the workstations. This spacing provides even distribution of sunlight over the workstations thus limiting the number of fluorescent lights needed. The skylights should be made out of polycarbonate. This material is the strongest of the three standard materials, has a high resistance to heat transmission, and still transmits a good quality of visible light.

A final consideration is the maintenance of the lights. The first step in maintenance is developing a schedule. This schedule should include replacement and cleaning of the lights. The factory should be divided into four or five sections. These sections should be about the same size and the lights should all be in close proximity. On a rotating weekly basis, these sections should be maintained. This maintenance includes replacing all burnt out bulbs and cleaning all of the bulbs and fixtures. The cleaning involves wiping down the lights with a dry rag to remove any dirt and dust that has accumulated. Old lamps and dirt on fixtures, lamps, and other surfaces can reduce the total illumination by 50 percent or more while full power is still being drawn by the lamps ("Energy Efficient Lighting," July 2, 1998).

Chapter VI

Appendices

Appendix A

Mission and Organization of Atlas Eléctrica

Atlas Industrial S.A., a subsidiary of Atlas Eléctrica, is an original Costa Rican manufacturing company with thirty-eight years of experience. Atlas produces 400 refrigerators and 350 ranges a day. Atlas sells these appliances in Costa Rica as well as exporting them to other Central American countries, South America, the Caribbean, and Mexico.

AB Electrolux, the largest manufacturer of kitchen appliances, bought twenty percent of Atlas Industrial's stock in 1996. This sale presents Atlas many new advantages including a bigger market, higher quality raw materials, and new technologies. Based on these developments, Atlas predicts a thirty percent increase in sales in 1998.

The net sales of Atlas Industrial in 1997 were 8,841,308,000 colones (US $31,918,000). After spending and taxes, Atlas's net earnings were 881,667,000 colones (US $3,183,000). This profit was a 173,935,000 colones (US $628,000) increase over the earnings in 1996.

Atlas consumes approximately 450,000 kWh of energy each month. This amount of energy costs Atlas 8,000,000 colones (US $29,000). See Appendix G for billing records.

Atlas's plant is divided in to four main sections. The metal mechanic section is used for cutting, molding, and stamping metal. Painting, pickling, phosphating, zinc plating, and porcelain coating are all done in the coating section. In the assembly section, the cabinet are assembled, thermoformed, and installed with isolating foaming. Plastic injection, the final section, is where the plastic parts are injected.

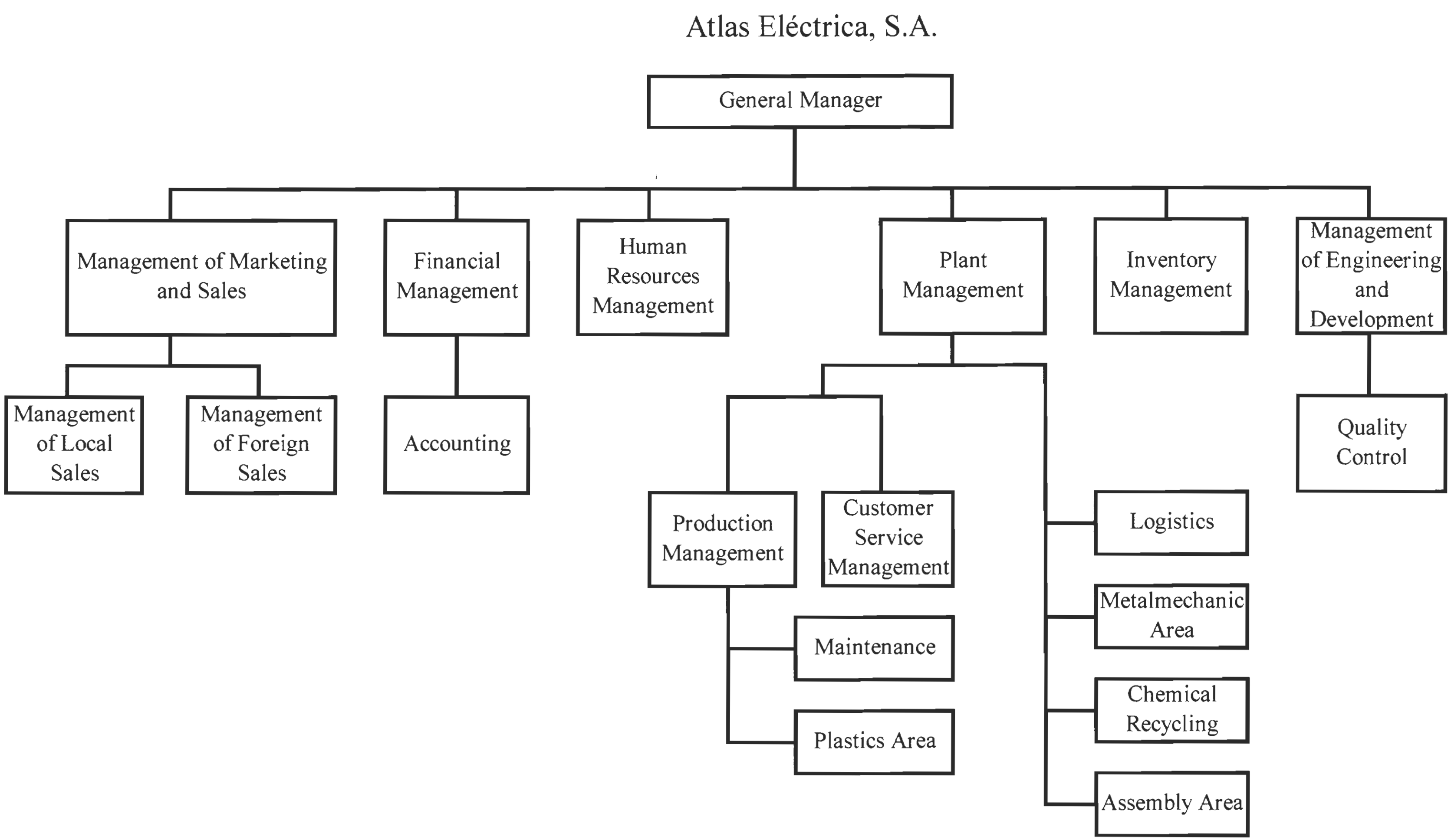
The vision of Atlas is to be a leader in its market and have its products be competitive throughout the world. Atlas' mission is to improve the quality of life of its consumers through the design, manufacture, and marketing of its products. To achieve this objective, Atlas is striving to protect the interests of its customers, employees, and shareholders. The company is accomplishing this goal by developing its human resources while continuing to preserve the environment.

The Montreal Protocol set forth a deadline for changing the CFC in refrigerators to ozone friendly gases by the year 2005. In 1998, Atlas changed to ozone friendly gases and set an example for the rest of the manufacturing world.

Atlas also opened four new service centers in Costa Rica in 1998. To better serve their foreign market, they also have centers in Guatemala, El Salvador, Honduras, and Nicaragua. All the employees of these centers are trained by Atlas employees who work in their Costa Rican plants.

Through our analysis of the lighting structure, the interests of the employees and the environment are addressed directly. Our main contacts within Atlas are Julio Zúñiga, Project Engineer, Pablo Solís, Facility and Machinery Maintenance, and Edwin Cardoza, Maintenance. See Figure A.1 for Atlas's management structure.

Figure A.1: Atlas Eléctrica's Management Structure



Source: Atlas Eléctrica, S.A. Organigrama 5 July 1999

Appendix B

Glossary

Ampere (A) – the standard unit for measuring the strength of an electric current.

Ballast – a device that controls the electricity used by a unit for starting and circuit protection

Cogeneration – the serial production of heat and electrical or mechanical power via the same primary fuel. Also known as in-plant power generation systems, dual energy use systems, waste-heat utilization systems, and total-energy systems.

Electric current - the motion of an electrical charge from one region to another.

Electric potential - the stored electric energy in an object.

Horsepower - a unit of power that gives the rate at which work is being done. It equals 33,000 foot pound (ft-lb) per minute (Smith, 1979, p. 210).

Kilovoltamps-reactive (kVAR) - unit in which magnetizing current is measured in. Not much useful work is done, but it is a necessary in the functioning of equipment (Zackrison, 1984, p. 26).

KiloWatt-hours (kWh) - one kW of energy being used continuously for one hour (Smith, 1979, p. 210). It is used in measuring the energy used by a consumer.

Load - amount of electricity for a given time.

Lux – a standard unit of light measurement, indicating the brightness of a light source

Meter-kilogram-second system (mks) – standard metric unit with length, mass, and time as fundamental qualities.

Power factor – real power/apparent power = W (watts)/VA (volts x amperes)

Power surge – an increase of voltage or current that has a short duration, approximately a few milliseconds, and high magnitude.

Primary transformer - the winding that receives the power from the electrical lines.

Secondary transformers - the winding that delivers the power to the rest of the factory.

Synchronizing – the process of correctly closing a circuit breaker by either manual or computerized means.

Transformer - used to change the voltage in the wires to the voltage needed for use in the factory. It is made up of two windings or coils, around the same core, but insulated from each other.

Volt (V) – the mks unit of electromotive force or difference in potential between two points in electric field that requires one joule of work to move a positive charge of one coulomb from the point of lower potential to the point of higher potential.

Volt-ampere - the apparent power; V times A.

Watt (W) – the mks unit of electrical power, equal to 1/746 of a horsepower.

Appendix C

Light Usage

Light Usage – Morning 1

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	10	Metal Mechanic 1	5/19/99	10:45
Bulb	26	0	Metal Mechanic 1	5/19/99	10:45
Fluorescent	78	7	Metal Mechanic 2	5/19/99	10:45
Bulb	3	0	Metal Mechanic 2	5/19/99	10:45
Fluorescent	41	5	Metal Mechanic 3	5/19/99	10:50
Fluorescent	24	12	Painting	5/19/99	10:50
Fluorescent	12	11	Outside Painting	5/19/99	10:50
Fluorescent	26	15	Assembly Line 1	5/19/99	11:05
Fluorescent	82	58	Corner Section-fridge	5/19/99	11:10
Bulb	1	0	Corner Section-fridge	5/19/99	11:10
Fluorescent	40	28	Assembly Line 2	5/19/99	11:10
Bulb	2	0	Assembly Line 2	5/19/99	11:10
Fluorescent	44	34	Stove Oven	5/21/99	9:40
Fluorescent	23	14	Center Bottom Floor	5/21/99	9:40
Bulb	4	0	Center Bottom Floor	5/21/99	9:40
Fluorescent	42	41	Middle Back Section-fridge	5/21/99	9:35
Fluorescent	38	35	Testing Area	5/21/99	10:05
Fluorescent	7	7	Section 1525	5/21/99	10:05
Fluorescent	46	11	Stove Assembly	5/21/99	9:55
Fluorescent	9	4	Packaging	5/21/99	9:55
Bulb	1	0	Packaging	5/21/99	9:55

	Total #	Total # on	% on
Fluorescent	537	292	54.38%
Sodium	37	0	0.00%
Total	574	292	50.87%

Light Usage – Morning 2

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	10	Metal Mechanic 1	6/7/99	9:20
Bulb	26	0	Metal Mechanic 1	6/7/99	9:20
Fluorescent	78	13	Metal Mechanic 2	6/7/99	9:25
Bulb	3	0	Metal Mechanic 2	6/7/99	9:25
Fluorescent	41	6	Metal Mechanic 3	6/7/99	9:25
Fluorescent	24	11	Painting	6/7/99	9:30
Fluorescent	12	10	Outside Painting	6/7/99	9:30
Fluorescent	26	6	Assembly Line 1	6/7/99	9:30
Fluorescent	82	18	Corner Section-fridge	6/7/99	9:40
Bulb	1	0	Corner Section-fridge	6/7/99	9:40
Fluorescent	40	4	Assembly Line 2	6/7/99	9:35
Bulb	2	0	Assembly Line 2	6/7/99	9:35
Fluorescent	44	23	Stove Oven	6/7/99	10:05
Fluorescent	23	22	Center Bottom Floor	6/7/99	9:55
Bulb	4	4	Center Bottom Floor	6/7/99	9:55
Fluorescent	42	37	Middle Back Section-Fridge	6/7/99	9:45
Fluorescent	38	37	Testing Area	6/7/99	9:15
Fluorescent	7	7	Section 1525	6/7/99	9:15
Fluorescent	46	43	Stove Assembly	6/7/99	9:50
Fluorescent	9	1	Packaging	6/7/99	9:45
Bulb	1	1	Packaging	6/7/99	9:45

	Total #	Total # on	% on
Fluorescent	537	248	46.18%
Sodium	37	5	13.51%
Total	574	253	44.08%

Light Usage – Morning 3

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	7	Metal Mechanic 1	6/14/99	9:05
Bulb	26	0	Metal Mechanic 1	6/14/99	9:05
Fluorescent	78	9	Metal Mechanic 2	6/14/99	9:10
Bulb	3	0	Metal Mechanic 2	6/14/99	9:10
Fluorescent	41	15	Metal Mechanic 3	6/14/99	9:10
Fluorescent	24	11	Painting	6/14/99	9:05
Fluorescent	12	9	Outside Painting	6/14/99	9:05
Fluorescent	26	20	Assembly Line 1	6/14/99	9:10
Fluorescent	82	46	Corner Section-fridge	6/14/99	9:10
Bulb	1	0	Corner Section-fridge	6/14/99	9:10
Fluorescent	40	20	Assembly Line 2	6/14/99	9:10
Bulb	2	0	Assembly Line 2	6/14/99	9:10
Fluorescent	44	26	Stove Oven	6/14/99	9:15
Fluorescent	23	23	Center Bottom Floor	6/14/99	9:15
Bulb	4	0	Center Bottom Floor	6/14/99	9:15
Fluorescent	42	37	Middle Back Section-Fridge	6/14/99	9:00
Fluorescent	38	37	Testing Area	6/14/99	9:00
Fluorescent	7	7	Section 1525	6/14/99	9:00
Fluorescent	46	45	Stove Assembly	6/14/99	9:00
Fluorescent	9	1	Packaging	6/14/99	9:05
Bulb	1	0	Packaging	6/14/99	9:05

	Total #	Total # on	% on
Fluorescent	537	313	58.29%
Sodium	37	0	0.00%
Total	574	313	54.53%

Light Usage – Midday 1

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	11	Metal Mechanic 1	6/1/99	12:20
Bulb	26	0	Metal Mechanic 1	6/1/99	12:20
Fluorescent	78	26	Metal Mechanic 2	6/1/99	12:25
Bulb	3	0	Metal Mechanic 2	6/1/99	12:25
Fluorescent	41	0	Metal Mechanic 3	6/1/99	12:25
Fluorescent	24	11	Painting	6/7/99	12:10
Fluorescent	12	9	Outside Painting	6/7/99	12:10
Fluorescent	26	9	Assembly Line 1	6/7/99	12:05
Fluorescent	82	18	Corner Section-fridge	6/7/99	12:05
Bulb	1	0	Corner Section-fridge	6/7/99	12:05
Fluorescent	40	12	Assembly Line 2	6/7/99	12:05
Bulb	2	0	Assembly Line 2	6/7/99	12:05
Fluorescent	44	26	Stove Oven	6/7/99	12:15
Fluorescent	23	23	Center Bottom Floor	6/7/99	12:15
Bulb	4	4	Center Bottom Floor	6/7/99	12:15
Fluorescent	42	37	Middle Back Section-Fridge	6/7/99	12:00
Fluorescent	38	37	Testing Area	6/7/99	12:00
Fluorescent	7	7	Section 1525	6/7/99	12:00
Fluorescent	46	43	Stove Assembly	6/7/99	12:00
Fluorescent	9	3	Packaging	6/7/99	12:00
Bulb	1	0	Packaging	6/7/99	12:00

	Total #	Total # on	% on
Fluorescent	537	272	50.65%
Sodium	37	4	10.81%
Total	574	276	48.08%

Light Usage – Midday 2

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	10	Metal Mechanic 1	6/3/99	2:00
Bulb	26	0	Metal Mechanic 1	6/3/99	2:00
Fluorescent	78	10	Metal Mechanic 2	6/3/99	2:00
Bulb	3	0	Metal Mechanic 2	6/3/99	2:00
Fluorescent	41	3	Metal Mechanic 3	6/3/99	2:00
Fluorescent	24	22	Painting	6/3/99	2:00
Fluorescent	12	9	Outside Painting	6/3/99	2:00
Fluorescent	26	17	Assembly Line 1	6/3/99	1:00
Fluorescent	82	51	Corner Section-fridge	6/3/99	12:45
Bulb	1	0	Corner Section-fridge	6/3/99	12:45
Fluorescent	40	10	Assembly Line 2	6/3/99	12:50
Bulb	2	0	Assembly Line 2	6/3/99	12:50
Fluorescent	44	22	Stove Oven	6/3/99	1:45
Fluorescent	23	23	Center Bottom Floor	6/3/99	1:45
Bulb	4	0	Center Bottom Floor	6/3/99	1:45
Fluorescent	42	34	Middle Back Section-Fridge	6/3/99	12:55
Fluorescent	38	38	Testing Area	6/3/99	12:30
Fluorescent	7	7	Section 1525	6/3/99	12:30
Fluorescent	46	43	Stove Assembly	6/3/99	12:35
Fluorescent	9	1	Packaging	6/3/99	1:35
Bulb	1	0	Packaging	6/3/99	1:35

	Total #	Total # on	% on
Fluorescent	537	300	55.87%
Sodium	37	0	0.00%
Total	574	300	52.26%

Light Usage – Midday 3

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	11	Metal Mechanic 1	6/8/99	1:25
Bulb	26	0	Metal Mechanic 1	6/8/99	1:25
Fluorescent	78	9	Metal Mechanic 2	6/8/99	1:25
Bulb	3	0	Metal Mechanic 2	6/8/99	1:25
Fluorescent	41	0	Metal Mechanic 3	6/8/99	1:25
Fluorescent	24	11	Painting	6/8/99	1:15
Fluorescent	12	9	Outside Painting	6/8/99	1:15
Fluorescent	26	9	Assembly Line 1	6/8/99	1:20
Fluorescent	82	40	Corner Section-fridge	6/8/99	1:20
Bulb	1	0	Corner Section-fridge	6/8/99	1:20
Fluorescent	40	12	Assembly Line 2	6/8/99	1:20
Bulb	2	0	Assembly Line 2	6/8/99	1:20
Fluorescent	44	23	Stove Oven	6/8/99	1:15
Fluorescent	23	23	Center Bottom Floor	6/8/99	1:15
Bulb	4	0	Center Bottom Floor	6/8/99	1:15
Fluorescent	42	37	Middle Back Section-Fridge	6/8/99	1:15
Fluorescent	38	38	Testing Area	6/8/99	1:15
Fluorescent	7	7	Section 1525	6/8/99	1:15
Fluorescent	46	43	Stove Assembly	6/8/99	1:15
Fluorescent	9	3	Packaging	6/8/99	1:15
Bulb	1	0	Packaging	6/8/99	1:15

	Total #	Total # on	% on
Fluorescent	537	275	51.21%
Sodium	37	0	0.00%
Total	574	275	47.91%

Light Usage – Afternoon 1

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	12	Metal Mechanic 1	6/7/99	3:00
Bulb	26	0	Metal Mechanic 1	6/7/99	3:00
Fluorescent	78	39	Metal Mechanic 2	6/7/99	3:00
Bulb	3	0	Metal Mechanic 2	6/7/99	3:00
Fluorescent	41	19	Metal Mechanic 3	6/7/99	3:00
Fluorescent	24	11	Painting	6/7/99	3:05
Fluorescent	12	9	Outside Painting	6/7/99	3:05
Fluorescent	26	16	Assembly Line 1	6/7/99	3:00
Fluorescent	82	41	Corner Section-fridge	6/7/99	3:00
Bulb	1	0	Corner Section-fridge	6/7/99	3:00
Fluorescent	40	22	Assembly Line 2	6/7/99	3:00
Bulb	2	0	Assembly Line 2	6/7/99	3:00
Fluorescent	44	23	Stove Oven	6/7/99	3:00
Fluorescent	23	23	Center Bottom Floor	6/7/99	3:00
Bulb	4	4	Center Bottom Floor	6/7/99	3:00
Fluorescent	42	37	Middle Back Section-Fridge	6/7/99	3:00
Fluorescent	38	38	Testing Area	6/7/99	3:05
Fluorescent	7	7	Section 1525	6/7/99	3:00
Fluorescent	46	45	Stove Assembly	6/7/99	3:00
Fluorescent	9	9	Packaging	6/7/99	3:05
Bulb	1	0	Packaging	6/7/99	3:05

	Total #	Total # on	% on
Fluorescent	537	351	65.36%
Sodium	37	4	10.81%
Total	574	355	61.85%

Light Usage – Afternoon 2

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	6	Metal Mechanic 1	6/8/99	3:40
Bulb	26	0	Metal Mechanic 1	6/8/99	3:40
Fluorescent	78	25	Metal Mechanic 2	6/8/99	3:45
Bulb	3	0	Metal Mechanic 2	6/8/99	3:45
Fluorescent	41	2	Metal Mechanic 3	6/8/99	3:45
Fluorescent	24	11	Painting	6/8/99	3:40
Fluorescent	12	9	Outside Painting	6/8/99	3:40
Fluorescent	26	4	Assembly Line 1	6/8/99	3:50
Fluorescent	82	37	Corner Section-fridge	6/8/99	3:50
Bulb	1	0	Corner Section-fridge	6/8/99	3:50
Fluorescent	40	7	Assembly Line 2	6/8/99	3:50
Bulb	2	0	Assembly Line 2	6/8/99	3:50
Fluorescent	44	23	Stove Oven	6/8/99	3:35
Fluorescent	23	23	Center Bottom Floor	6/8/99	3:35
Bulb	4	0	Center Bottom Floor	6/8/99	3:35
Fluorescent	42	37	Middle Back Section-Fridge	6/8/99	3:40
Fluorescent	38	38	Testing Area	6/8/99	3:35
Fluorescent	7	7	Section 1525	6/8/99	3:35
Fluorescent	46	43	Stove Assembly	6/8/99	3:40
Fluorescent	9	1	Packaging	6/8/99	3:40
Bulb	1	0	Packaging	6/8/99	3:40

	Total #	Total # on	% on
Fluorescent	537	273	50.84%
Sodium	37	0	0.00%
Total	574	273	47.56%

Light Usage – Afternoon 3

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	4	Metal Mechanic 1	6/10/99	3:15
Bulb	26	7	Metal Mechanic 1	6/10/99	3:15
Fluorescent	78	63	Metal Mechanic 2	6/10/99	2:20
Bulb	3	3	Metal Mechanic 2	6/10/99	3:20
Fluorescent	41	39	Metal Mechanic 3	6/10/99	3:20
Fluorescent	24	11	Painting	6/10/99	3:15
Fluorescent	12	9	Outside Painting	6/10/99	3:15
Fluorescent	26	12	Assembly Line 1	6/10/99	3:15
Fluorescent	82	40	Corner Section-fridge	6/10/99	3:15
Bulb	1	0	Corner Section-fridge	6/10/99	3:15
Fluorescent	40	20	Assembly Line 2	6/10/99	3:15
Bulb	2	0	Assembly Line 2	6/10/99	3:15
Fluorescent	44	26	Stove Oven	6/10/99	3:10
Fluorescent	23	23	Center Bottom Floor	6/10/99	3:10
Bulb	4	0	Center Bottom Floor	6/10/99	3:10
Fluorescent	42	8	Middle Back Section-Fridge	6/10/99	3:10
Fluorescent	38	38	Testing Area	6/10/99	3:15
Fluorescent	7	7	Section 1525	6/10/99	3:15
Fluorescent	46	45	Stove Assembly	6/10/99	3:15
Fluorescent	9	9	Packaging	6/10/99	3:15
Bulb	1	0	Packaging	6/10/99	3:15

	Total #	Total # on	% on
Fluorescent	537	354	65.92%
Sodium	37	10	27.03%
Total	574	364	63.41%

Light Usage – Evening 1

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	8	Metal Mechanic 1	6/8/99	5:30
Bulb	26	6	Metal Mechanic 1	6/8/99	5:30
Fluorescent	78	63	Metal Mechanic 2	6/8/99	5:30
Bulb	3	3	Metal Mechanic 2	6/8/99	5:30
Fluorescent	41	32	Metal Mechanic 3	6/8/99	5:35
Fluorescent	24	11	Painting	6/8/99	5:25
Fluorescent	12	9	Outside Painting	6/8/99	5:25
Fluorescent	26	4	Assembly Line 1	6/8/99	5:30
Fluorescent	82	38	Corner Section-fridge	6/8/99	5:25
Bulb	1	0	Corner Section-fridge	6/8/99	5:25
Fluorescent	40	7	Assembly Line 2	6/8/99	5:35
Bulb	2	0	Assembly Line 2	6/8/99	5:35
Fluorescent	44	23	Stove Oven	6/8/99	5:30
Fluorescent	23	23	Center Bottom Floor	6/8/99	5:30
Bulb	4	0	Center Bottom Floor	6/8/99	5:30
Fluorescent	42	37	Middle Back Section-Fridge	6/8/99	5:30
Fluorescent	38	38	Testing Area	6/8/99	5:25
Fluorescent	7	7	Section 1525	6/8/99	5:25
Fluorescent	46	43	Stove Assembly	6/8/99	5:25
Fluorescent	9	1	Packaging	6/8/99	5:25
Bulb	1	0	Packaging	6/8/99	5:25

	Total #	Total # on	% on
Fluorescent	537	344	64.06%
Sodium	37	9	24.32%
Total	574	353	61.50%

Light Usage – Evening 2

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	4	Metal Mechanic 1	6/10/99	5:25
Bulb	26	7	Metal Mechanic 1	6/10/99	5:25
Fluorescent	78	63	Metal Mechanic 2	6/10/99	5:25
Bulb	3	3	Metal Mechanic 2	6/10/99	5:25
Fluorescent	41	32	Metal Mechanic 3	6/10/99	5:30
Fluorescent	24	11	Painting	6/10/99	5:30
Fluorescent	12	9	Outside Painting	6/10/99	5:30
Fluorescent	26	12	Assembly Line 1	6/10/99	5:30
Fluorescent	82	40	Corner Section-fridge	6/10/99	5:35
Bulb	1	0	Corner Section-fridge	6/10/99	5:35
Fluorescent	40	21	Assembly Line 2	6/10/99	5:30
Bulb	2	0	Assembly Line 2	6/10/99	5:30
Fluorescent	44	26	Stove Oven	6/10/99	5:35
Fluorescent	23	23	Center Bottom Floor	6/10/99	5:35
Bulb	4	0	Center Bottom Floor	6/10/99	5:35
Fluorescent	42	8	Middle Back Section-Fridge	6/10/99	5:35
Fluorescent	38	37	Testing Area	6/10/99	5:40
Fluorescent	7	7	Section 1525	6/10/99	5:40
Fluorescent	46	45	Stove Assembly	6/10/99	5:30
Fluorescent	9	7	Packaging	6/10/99	5:40
Bulb	1	0	Packaging	6/10/99	5:40

	Total #	Total # on	% on
Fluorescent	537	345	64.25%
Sodium	37	10	27.03%
Total	574	355	61.85%

Light Usage – Evening 3

Type of Light	Total #	# on	Location	Date	Time
Fluorescent	25	12	Metal Mechanic 1	6/15/99	5:50
Bulb	26	0	Metal Mechanic 1	6/15/99	5:50
Fluorescent	78	63	Metal Mechanic 2	6/15/99	5:55
Bulb	3	3	Metal Mechanic 2	6/15/99	5:55
Fluorescent	41	39	Metal Mechanic 3	6/15/99	5:55
Fluorescent	24	11	Painting	6/15/99	6:00
Fluorescent	12	9	Outside Painting	6/15/99	6:00
Fluorescent	26	22	Assembly Line 1	6/15/99	6:00
Fluorescent	82	49	Corner Section-fridge	6/15/99	6:05
Bulb	1	0	Corner Section-fridge	6/15/99	6:05
Fluorescent	40	17	Assembly Line 2	6/15/99	6:05
Bulb	2	0	Assembly Line 2	6/15/99	6:05
Fluorescent	44	26	Stove Oven	6/15/99	6:05
Fluorescent	23	23	Center Bottom Floor	6/15/99	6:05
Bulb	4	0	Center Bottom Floor	6/15/99	6:05
Fluorescent	42	37	Middle Back Section-Fridge	6/15/99	6:05
Fluorescent	38	37	Testing Area	6/15/99	6:05
Fluorescent	7	7	Section 1525	6/15/99	6:05
Fluorescent	46	45	Stove Assembly	6/15/99	6:05
Fluorescent	9	7	Packaging	6/15/99	6:05
Bulb	1	0	Packaging	6/15/99	6:05

	Total #	Total # on	% on
Fluorescent	537	404	75.23%
Sodium	37	3	8.11%
Total	574	407	70.91%

Appendix D

Light Readings in Factory

Light Readings – Morning 1

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	1750	6/16/99	9:05
Metal Mechanic 2	1880	320	6/16/99	9:05
Metal Mechanic 3	1438	1500	6/16/99	9:05
Painting	127	95	6/16/99	9:10
Outside Painting	75	380	6/16/99	9:10
Assembly Line 1	394	340	6/16/99	9:10
Corner Section-fridge	1594	370	6/16/99	9:20
Assembly Line 2	1134	900	6/16/99	9:10
Stove Oven	1400	60	6/16/99	9:20
Center Bottom Floor	723	30	6/16/99	9:20
Middle Back Section-Fridge	935	230	6/16/99	9:25
Testing Area	631	220	6/16/99	9:25
Section 1525	166	1150	6/16/99	9:25
Stove Assembly	1839	130	6/16/99	9:20
Packaging	577	550	6/16/99	9:15

Light Readings – Morning 2

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	2100	6/17/99	8:50
Metal Mechanic 2	1880	240	6/17/99	8:50
Metal Mechanic 3	1438	1100	6/17/99	8:50
Painting	127	70	6/17/99	8:55
Outside Painting	75	380	6/17/99	8:55
Assembly Line 1	394	330	6/17/99	8:55
Corner Section-fridge	1594	310	6/17/99	9:05
Assembly Line 2	1134	630	6/17/99	9:00
Stove Oven	1400	50	6/17/99	9:05
Center Bottom Floor	723	90	6/17/99	9:10
Middle Back Section-Fridge	935	220	6/17/99	9:10
Testing Area	631	900	6/17/99	9:10
Section 1525	166	290	6/17/99	9:10
Stove Assembly	1839	370	6/17/99	9:05
Packaging	577	240	6/17/99	9:05

Light Readings – Morning 3

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	1150	6/21/99	9:55
Metal Mechanic 2	1880	2700	6/21/99	9:55
Metal Mechanic 3	1438	3600	6/21/99	9:55
Painting	127	90	6/21/99	10:00
Outside Painting	75	330	6/21/99	10:00
Assembly Line 1	394	290	6/21/99	10:00
Corner Section-fridge	1594	400	6/21/99	10:10
Assembly Line 2	1134	870	6/21/99	10:15
Stove Oven	1400	60	6/21/99	10:15
Center Bottom Floor	723	35	6/21/99	10:10
Middle Back Section-Fridge	935	270	6/21/99	10:10
Testing Area	631	1350	6/21/99	10:15
Section 1525	166	220	6/21/99	10:05
Stove Assembly	1839	140	6/21/99	10:05
Packaging	577	3100	6/21/99	10:05

Light Readings – Midday 1

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	1000	6/16/99	12:05
Metal Mechanic 2	1880	260	6/16/99	12:05
Metal Mechanic 3	1438	2450	6/16/99	12:05
Painting	127	90	6/16/99	12:10
Outside Painting	75	350	6/16/99	12:10
Assembly Line 1	394	340	6/16/99	12:10
Corner Section-fridge	1594	270	6/16/99	12:20
Assembly Line 2	1134	900	6/16/99	12:10
Stove Oven	1400	50	6/16/99	12:15
Center Bottom Floor	723	40	6/16/99	12:20
Middle Back Section-Fridge	935	260	6/16/99	12:20
Testing Area	631	220	6/16/99	12:25
Section 1525	166	750	6/16/99	12:25
Stove Assembly	1839	180	6/16/99	12:15
Packaging	577	320	6/16/99	12:15

Light Readings – Midday 2

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	800	6/17/99	12:00
Metal Mechanic 2	1880	280	6/17/99	12:00
Metal Mechanic 3	1438	1730	6/17/99	12:00
Painting	127	70	6/17/99	12:00
Outside Painting	75	410	6/17/99	12:00
Assembly Line 1	394	250	6/17/99	12:05
Corner Section-fridge	1594	250	6/17/99	12:15
Assembly Line 2	1134	1510	6/17/99	12:05
Stove Oven	1400	50	6/17/99	12:10
Center Bottom Floor	723	80	6/17/99	12:15
Middle Back Section-Fridge	935	180	6/17/99	12:15
Testing Area	631	590	6/17/99	12:15
Section 1525	166	210	6/17/99	12:15
Stove Assembly	1839	190	6/17/99	12:10
Packaging	577	1680	6/17/99	12:10

Light Readings – Midday 3

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	920	6/21/99	12:00
Metal Mechanic 2	1880	510	6/21/99	12:00
Metal Mechanic 3	1438	2700	6/21/99	12:00
Painting	127	80	6/21/99	12:05
Outside Painting	75	300	6/21/99	12:05
Assembly Line 1	394	250	6/21/99	12:05
Corner Section-fridge	1594	260	6/21/99	12:20
Assembly Line 2	1134	1350	6/21/99	12:20
Stove Oven	1400	80	6/21/99	12:15
Center Bottom Floor	723	30	6/21/99	12:15
Middle Back Section-Fridge	935	210	6/21/99	12:15
Testing Area	631	600	6/21/99	12:00
Section 1525	166	190	6/21/99	12:15
Stove Assembly	1839	140	6/21/99	12:10
Packaging	577	3200	6/21/99	12:10

Light Readings – Afternoon 1

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	550	6/15/99	3:10
Metal Mechanic 2	1880	140	6/15/99	3:10
Metal Mechanic 3	1438	1090	6/15/99	3:10
Painting	127	90	6/15/99	3:15
Outside Painting	75	400	6/15/99	3:15
Assembly Line 1	394	320	6/15/99	3:20
Corner Section-fridge	1594	190	6/15/99	3:30
Assembly Line 2	1134	230	6/15/99	3:20
Stove Oven	1400	55	6/15/99	3:30
Center Bottom Floor	723	80	6/15/99	3:35
Middle Back Section-Fridge	935	160	6/15/99	3:35
Testing Area	631	460	6/15/99	3:35
Section 1525	166	215	6/15/99	3:35
Stove Assembly	1839	110	6/15/99	3:25
Packaging	577	1250	6/15/99	3:25

Light Readings – Afternoon 2

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	170	6/16/99	3:10
Metal Mechanic 2	1880	240	6/16/99	3:10
Metal Mechanic 3	1438	600	6/16/99	3:10
Painting	127	390	6/16/99	3:15
Outside Painting	75	400	6/16/99	3:15
Assembly Line 1	394	300	6/16/99	3:15
Corner Section-fridge	1594	160	6/16/99	3:25
Assembly Line 2	1134	190	6/16/99	3:15
Stove Oven	1400	40	6/16/99	3:20
Center Bottom Floor	723	20	6/16/99	3:25
Middle Back Section-Fridge	935	150	6/16/99	3:25
Testing Area	631	200	6/16/99	3:25
Section 1525	166	150	6/16/99	3:25
Stove Assembly	1839	80	6/16/99	3:20
Packaging	577	490	6/16/99	3:20

Light Readings – Afternoon 3

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	30	6/17/99	3:10
Metal Mechanic 2	1880	160	6/17/99	3:10
Metal Mechanic 3	1438	150	6/17/99	3:10
Painting	127	90	6/17/99	3:15
Outside Painting	75	370	6/17/99	3:15
Assembly Line 1	394	250	6/17/99	3:15
Corner Section-fridge	1594	10	6/17/99	3:25
Assembly Line 2	1134	70	6/17/99	3:15
Stove Oven	1400	50	6/17/99	3:25
Center Bottom Floor	723	20	6/17/99	3:25
Middle Back Section-Fridge	935	60	6/17/99	3:25
Testing Area	631	110	6/17/99	3:25
Section 1525	166	170	6/17/99	3:25
Stove Assembly	1839	90	6/17/99	3:20
Packaging	577	70	6/17/99	3:20

Light Readings – Evening 1

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	10	6/15/99	5:45
Metal Mechanic 2	1880	160	6/15/99	5:45
Metal Mechanic 3	1438	140	6/15/99	5:50
Painting	127	90	6/15/99	5:50
Outside Painting	75	415	6/15/99	5:50
Assembly Line 1	394	310	6/15/99	5:50
Corner Section-fridge	1594	80	6/15/99	5:55
Assembly Line 2	1134	80	6/15/99	5:50
Stove Oven	1400	50	6/15/99	5:55
Center Bottom Floor	723	80	6/15/99	6:00
Middle Back Section-Fridge	935	90	6/15/99	6:00
Testing Area	631	100	6/15/99	6:00
Section 1525	166	190	6/15/99	6:00
Stove Assembly	1839	60	6/15/99	5:55
Packaging	577	35	6/15/99	5:55

Light Readings – Evening 2

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	10	6/16/99	6:00
Metal Mechanic 2	1880	150	6/16/99	6:00
Metal Mechanic 3	1438	140	6/16/99	6:00
Painting	127	80	6/16/99	6:05
Outside Painting	75	380	6/16/99	6:05
Assembly Line 1	394	290	6/16/99	6:05
Corner Section-fridge	1594	130	6/16/99	6:10
Assembly Line 2	1134	60	6/16/99	6:05
Stove Oven	1400	40	6/16/99	6:10
Center Bottom Floor	723	30	6/16/99	6:10
Middle Back Section-Fridge	935	90	6/16/99	6:10
Testing Area	631	200	6/16/99	6:10
Section 1525	166	100	6/16/99	6:10
Stove Assembly	1839	60	6/16/99	6:10
Packaging	577	20	6/16/99	6:10

Light Readings – Evening 3

Section	Area (m^2)	Reading (Lux)	Day	Time
Metal Mechanic 1	1880	210	6/17/99	6:10
Metal Mechanic 2	1880	150	6/17/99	6:10
Metal Mechanic 3	1438	140	6/17/99	6:10
Painting	127	10	6/17/99	6:10
Outside Painting	75	380	6/17/99	6:10
Assembly Line 1	394	250	6/17/99	6:10
Corner Section-fridge	1594	10	6/17/99	6:15
Assembly Line 2	1134	80	6/17/99	6:15
Stove Oven	1400	50	6/17/99	6:15
Center Bottom Floor	723	20	6/17/99	6:15
Middle Back Section-Fridge	935	70	6/17/99	6:15
Testing Area	631	110	6/17/99	6:15
Section 1525	166	220	6/17/99	6:20
Stove Assembly	1839	60	6/17/99	6:20
Packaging	577	30	6/17/99	6:15

Appendix E

Light Reading Comparisons

Section	Time of Day	Average Light Reading	Average % Lights on	# of Skylights
Metal Mechanic 1	Morning	1666.7	17.6%	55
	Midday	906.7	21.0%	55
	Afternoon	250.0	19.0%	55
	Evening	76.7	24.1%	55
Metal Mechanic 2	Morning	1086.7	12.0%	69
	Midday	350.0	18.5%	69
	Afternoon	180.0	53.5%	69
	Evening	153.3	81.5%	69
Metal Mechanic 3	Morning	2066.7	21.2%	56
	Midday	2293.3	2.4%	56
	Afternoon	613.3	48.8%	56
	Evening	573.3	83.7%	56
Painting	Morning	85.0	47.1%	0
	Midday	80.0	61.3%	0
	Afternoon	190.0	45.8%	0
	Evening	60.0	45.8%	0
Outside Painting	Morning	363.3	89.2%	2
	Midday	353.3	75.0%	2
	Afternoon	390.0	75.0%	2
	Evening	391.7	75.0%	2
Assembly Line 1	Morning	320.0	52.7%	3
	Midday	280.0	45.0%	3
	Afternoon	290.0	41.2%	3
	Evening	283.3	48.8%	3
Corner Section-fridge	Morning	360.0	49.0%	6
	Midday	260.0	43.7%	6
	Afternoon	120.0	47.3%	6
	Evening	73.3	45.5%	6
Assembly Line 2	Morning	890.0	41.2%	7
	Midday	1253.3	26.9%	7
	Afternoon	163.3	38.8%	7
	Evening	73.3	35.7%	7

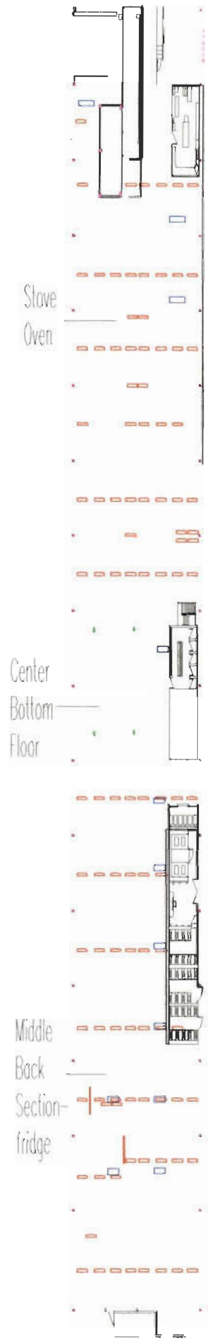
Light Reading Comparisons, continued

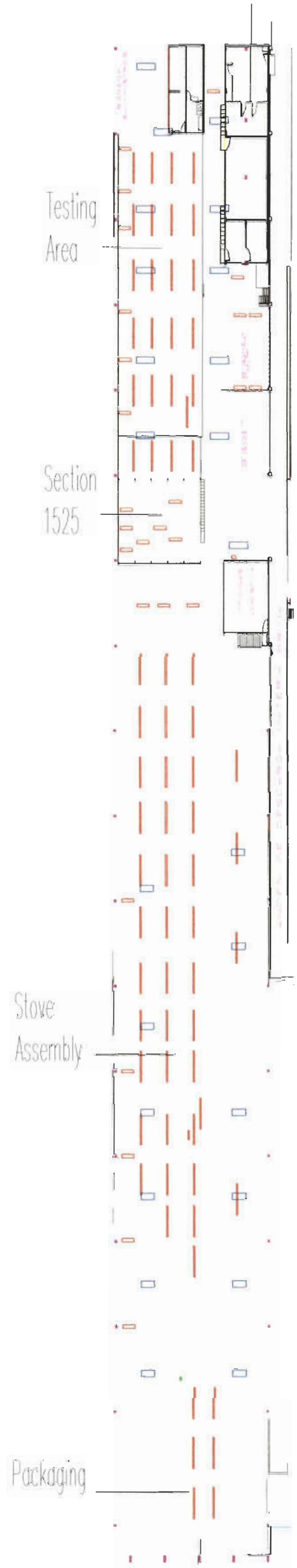
Section	Time of Day	Average Light Reading	Average % Lights on	# of Skylights
Stove Oven	Morning	56.7	63.0%	4
	Midday	60.0	53.9%	4
	Afternoon	48.3	54.5%	4
	Evening	46.7	56.8%	4
Center Bottom Floor	Morning	51.7	77.8%	3
	Midday	50.0	90.0%	3
	Afternoon	40.0	90.0%	3
	Evening	43.3	85.2%	3
Middle Back Section-Fridge	Morning	240.0	91.2%	6
	Midday	216.7	85.7%	6
	Afternoon	123.3	65.0%	6
	Evening	83.3	65.0%	6
Testing Area	Morning	1133.3	69.2%	11
	Midday	646.7	99.2%	11
	Afternoon	240.0	100.0%	11
	Evening	103.3	98.2%	11
Section 1525	Morning	243.3	100.0%	0
	Midday	206.7	100.0%	0
	Afternoon	195.0	100.0%	0
	Evening	203.3	100.0%	0
Stove Assembly	Morning	213.3	71.7%	10
	Midday	170.0	93.5%	10
	Afternoon	93.3	96.3%	10
	Evening	60.0	96.3%	10
Packaging	Morning	1296.7	23.0%	2
	Midday	1733.3	23.0%	2
	Afternoon	603.3	63.0%	2
	Evening	28.3	50.0%	2

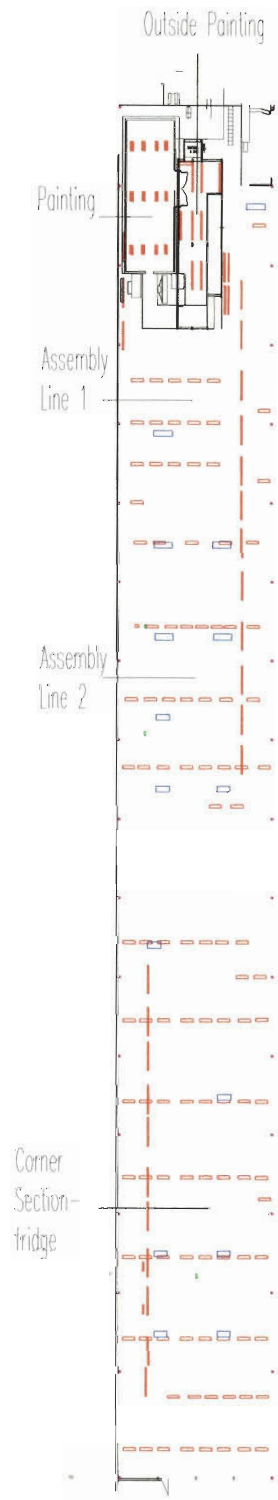
Appendix F

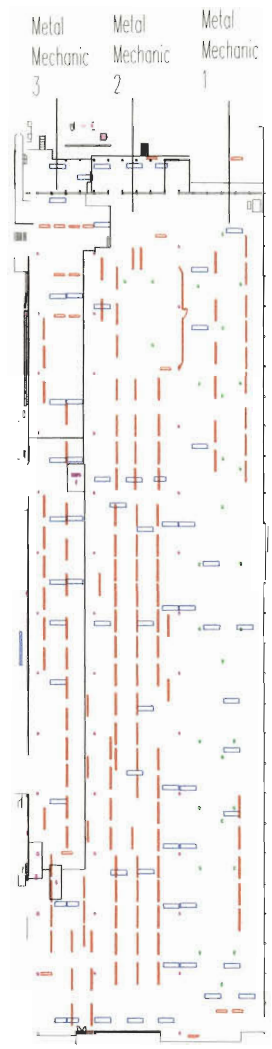
Floor Plans of Atlas Eléctrica

In the following drawings, the floor plan and the arrangement of lights and skylights are shown. The red rectangles are the fluorescent lights; the green circles are the sodium lights; the blue rectangles are the skylights. The magenta squares on the floor plans show the supporting columns of the building and the black lines are the internal and external walls of the factory.


Stove
Oven
Center
Bottom
Floor
Middle
Back
Section-
fridge


Testing Area
Section 1525
Stove Assembly
Packaging


Outside Painting
Painting
Assembly Line 1
Assembly Line 2
Corner Section-fridge


Metal Mechanic 3
Metal Mechanic 2
Metal Mechanic 1

Appendix G

Billing Records

Date	Total Energy	Demand	Cost for Energy	Demand Cost	Total Cost	Total Cost ($US)
24/4/99	405,288	1264.40	¢3,603,618.70	¢3,260,818.40	¢8,072,494.45	$ 28,830.34
23/3/99	422608	1264.40	¢3,756,034.60	¢3,260,818.40	¢8,249,296.90	$ 29,461.77
24/2/99	453784	1229.70	¢4,030,383.35	¢3,169,696.20	¢8,461,839.70	$ 30,220.86
23/1/99	311760	1160.40	¢2,780,572.45	¢2,987,714.40	¢7,083,539.40	$ 25,298.36
23/12/98	445124	1229.70	¢3,954,176.20	¢3,169,696.20	¢9,886,415.75	$ 35,308.63
23/11/98	524796	1247.00	¢4,462,739.10	¢3,103,164.50	¢10,669,977.25	$ 38,107.06
23/10/98	545580	1299.00	¢4,565,251.90	¢3,192,518.90	¢10,963,187.85	$ 39,154.24
24/9/98	457248	1299.00	¢3,832,095.70	¢3,192,518.90	¢9,812,486.30	$ 35,044.59
24/8/98	497084	1281.70	¢4,162,734.55	¢3,149,246.40	¢9,953,550.05	$ 35,548.39
24/7/98	448588	1281.70	¢3,760,218.20	¢3,149,246.40	¢8,124,726.25	$ 29,016.88
25/6/98	493620	1264.40	¢4,133,983.60	¢3,105,973.90	¢8,508,098.05	$ 30,386.06
25/5/98	453784	1264.40	¢3,803,344.60	¢3,105,973.90	¢8,120,436.85	$ 29,001.56
24/4/98	410484	1195.10	¢3,443,954.60	¢2,932,633.85	¢7,494,229.95	$ 26,765.11
23/3/98	439536	1195.10	¢3,602,086.45	¢2,932,633.85	¢7,677,662.95	$ 27,420.22
23/2/98	394896	1333.60	¢3,314,574.10	¢3,279,063.90	¢7,746,007.45	$ 27,664.31
23/1/98	287512	1004.60	¢2,423,287.70	¢2,456,136.20	¢5,757,519.05	$ 20,562.57
24/12/97	542116	1195.10	¢4,536,500.65	¢2,932,633.85	¢8,761,583.35	$ 31,291.37
24/11/97	529992	1229.70	¢4,435,871.65	¢3,019,178.80	¢8,745,245.85	$ 31,233.02
24/10/97	413948	1229.70	¢3,472,706.15	¢3,019,178.80	¢7,627,973.85	$ 27,242.76
24/9/97	382772	1160.40	¢3,213,945.35	¢2,845,838.70	¢7,126,736.85	$ 25,452.63
24/7/97	393164	1091.20	¢3,300,198.40	¢2,672,748.75	¢7,694,188.35	$ 27,479.24
24/6/97	427804	1143.10	¢3,587,711.10	¢2,802,566.25	¢8,237,161.95	$ 29,418.44
23/5/97	270192	1091.20	¢2,279,531.00	¢2,672,748.75	¢6,301,223.20	$ 22,504.37
24/4/97	258068	1004.60	¢2,178,901.60	¢2,456,136.20	¢5,912,617.80	$ 21,116.49
24/3/97	294440	1004.60	¢2,480,789.40	¢2,456,136.20	¢6,324,621.85	$ 22,587.94
24/2/97	332544	1004.60	¢2,418,832.65	¢2,115,204.20	¢6,012,709.35	$ 21,473.96
24/1/97	209572	1004.60	¢1,475,770.40	¢2,029,971.20	¢4,911,960.25	$ 17,542.72
23/12/96	289244	987.24	¢2,025,507.75	¢1,994,083.00	¢5,625,306.55	$ 20,090.38

*Energy unit = kW

Source: Atlas Eléctrica's Records

Chapter VII

References

Chapter VII.

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