Heating and Cooling:

A Retrofit of ES2

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ERS 250

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Table of Contents

1. INTRODUCTION:

1.1 BACKGROUND:

The main power supply on campus is originated from one main generating plant located at the north end of campus. Water is heated mainly by steam and natural gas, and cooled by electricity before being distributed throughout the university. This energy is distributed by a series of underground piping, which connects to all buildings on campus, including Environmental Studies 2 (Moore, 2004).

The environmental studies 2 building consists of a very intricate and complex HVAC system, one that is too long and complex to be explained within this project alone. Different parts of the building contain varying HVAC systems, but by singling out the HVAC system of ES 2’s second floor (architectural studio), it is still a very complex system, yet is easier to understand on a small-scale level.

The HVAC system was replaced 5 years ago and works on VAV- Variable Air Volume, consisting of heating and cooling coils. What this means is that airflow is controlled through thermostats and computer systems to vary the air output between different times of the day. Heating and cooling coils are contained in separate ductwork so they can be used independently for different areas to better control room temperature.
The duct work consists of terminal boxes, connecting to various thermostats located around the room(s), which controls vent boxes that more or less open and close as to the amount of heat needed (Zalagenas, 2004). When more heat is needed these boxes open and add heat to the area by means of warm air. Depending on the amount of heat needed

to raise the temperature of the area, indicated by the thermostat, the ducts will release more or less air into the area, according to predetermined, desirable temperatures.

When the area is in need of cooling i.e. in the summer, ducts will release cool air into the area, only if cool air is available. The system will use outside air during proper seasons for cooling, but once the outside air becomes unfavorable, cool water is cycled through cooling coils, and cold air is distributed from cooling ducts. All computers are set to a maximum air volume distribution and regulate these air exchanges throughout the day (Zalagenas, 2004).

The entire space houses a series of fans, which opens up the air flow to the area. These fans are linked back to the main computer system, which controls the speed at which the fans will operate. The fans are programmed to speed up or slow down to create a set point pressure in the air ducts. This in result means, i.e. for minimum air volume, the fan is working at minimal speed. Depending on the temperatures experienced and air pressure output, the fans/ducts will ramp (up or down), according to proper air exchange rates needed, and the necessity to conserve energy. This means that ducts are not running and pumping air at their maximum rates all day, they fluctuate with the changing temperatures exerted from machinery and human traffic (Zalagenas, 2004). The HVAC system of the area has a lower volume at night, due to less occupancy of humans and machinery, and a higher volume exchange during the day, when temperatures and ventilation need better regulation for students and staff in the building (Nolan, 2004).

Since the building is located in Canada, the cold winters create another twist to the whole system. Perimeter radiation is separate for the cold winter months. Cold air infiltrates from windows creating a lower heat gain from the walls and their interior radiation. Due to these pressure changes, adequate air exchange is regulated by a central computer system connected to the fans and ductwork. For example, during the winter there is a large heat load in the room; heating is high and there is still a need for high ventilation, yet the ducts slow down the air exchange to keep in the warm air. The air exchange is slowed because of the way the room temperature is raised by adding hot air. If temperatures remain at a high, little heat is added, and the existing warm air remains in the area, maintaining the desirable temperature (Zalagenas, 2004). Air exchange needs to take place, to renew the air for students and staff occupying the area. Though the exchange rates usually vary, a minimum exchange is attained through the vent boxes. Vent sizes are quite variable throughout the second floor, for they rely on room size and occupancy. Certain sized vents, according to room size make for better efficiency in ES 2. The main HVAC supply uses a “squirrel cage” fan, and the return system mainly consists of centrifugal fans (axial), both of which are energy savers (Zalagenas, 2004).

The ES 2 HVAC system is quite complex and this is only scratching the surface for one small area of the building. This again is a brief overview of the main HVAC system of the 2nd floor (architect studio), and hopefully makes sense as to how the existing system in place works and operates. With the approximate use of 29054237.9MJ in a year, or 74180.09MJ/day, it is easy to see that the vast amounts of energy consumed on campus needs to be conserved when possible (Moore, 2004). By making a complex HVAC system more efficient, energy conservation and steps towards sustainability will be achieved. For a general set up of an HVAC for large buildings, refer to Appendix A.

1.2 Purpose:

The purpose of this project is to develop a plan to renovate the 2nd floor of the ES2 building for future use by the Environment and Resource Studies faculty. The idea behind the renovations of ES2 is to create a more sustainable living environment that can be used for the Environmental Studies students. A more sustainable building will also lead to a more environmentally sound reputation for the faculty as well as the University of Waterloo. This project may also bring about other projects of its kind to take place. The definition of sustainability refers to the use of resources and materials in a way that does not compromise future uses of the area or materials. There are many areas of focus in making ES2 a more sustainable environment. This project examines the heating and cooling processes currently used in ES2 and the potential and feasibility of implementing new, or upgrading old heating and cooling methods, or implementing characteristics that would lead to the more efficient and effective heating and cooling of ES2.

2. Heating and Cooling Methods

The most natural form of energy for heating and cooling methods is the energy produced by the sun. For use of the sun's energy, the structural characteristics of the building are very important in order to enhance the use of the sun's energy to effectively heat or cool a building. Beams of sunlight coming through a window often provide a lot of heat for the room. Through careful planning of building characteristics the sun's energy will provide a comfortable living environment inside the structure.

Passive solar design is one method of using the sun's energy for heating and cooling. Passive solar design is often simple, requiring little maintenance and no mechanical systems, while being quite economical at the same time. Due to the fact that the sun produces heat, the heating technology is much more developed than the cooling technology (Sustainable Sources, 2004). The most effective passive solar designs comprehend the wind patterns, the terrain, vegetation, and solar exposure that encompass the building (Sustainable Sources, 2004).

Heating and cooling methods use the concepts of radiation, convection, and conduction through the absorption, transmission, or reflection of solar radiation by the building materials. Through these methods, there are five basic principles to examine for solar design, which includes building orientation, overhangs and shading, insulation, windows, and thermal mass (Sustainable Sources, 2004).

2.1 Building Orientation:

To take advantage of optimal solar energy the orientation of the building must be correct. The building should be elongated along the east/west axis making the larger sides of the building face south to capture the most intense solar energy (Sustainable Sources, 2004). Fortunately, with the inability to change the orientation of ES2, it is already placed along the east/west axis. Therefore, ES2 has potential to effectively use the energy of the sun for heating and cooling. In terms of interior orientation, open design will allow more effective heat transfer throughout the building.

2.2 Overhangs and Shading:

Economically, overhangs are the least costly. Overhangs on windows will provide shade, which will effectively diminish the amount of heat radiated through windows. Proper sized overhangs are very important to receive effective shading

(National Renewable Energy Laboratory, 2004). If the overhang is too short, the windows will not be shaded from the summer sun and the rooms facing south will become very warm (National Renewable Energy Laboratory, 2004). If the overhangs are too long, the sun's energy will not be able to pass through the windows in the winter, causing the areas to stay cooler (National Renewable Energy Laboratory, 2004). Other effective and very economical means of regulating the sun's energy from passing through windows are insulated curtains, awnings, exterior shades, and shutters. (Moore, 2004)

2.3 LANDSCAPING:

Outdoor landscaping can have a significant effect on the heating and cooling efficiency of a building. According to The Department of Energy "carefully positioned trees can save up to 25% of a household's energy consumption for heating and cooling" (EERE, 1995). It is noted that the above quote pertains to a house whereas ES2 is a larger building and the savings might not be at the same standard. However, since there has still been a significant impact on a house the impact on a larger building, such as ES2, could be considerable.

"Proper placement of only three trees will save an average household between $100 and $250 in energy costs annually" (EERE, 1995). If designed properly, there should be enough energy savings to return the initial investment in less than eight years. The implementations that could be introduced to improve the energy efficiency of ES2 are as follows: shading the building, shading the ground, and wind barriers.

Shading is the most effective means of cooling a building. It can reduce the air-conditioning costs by 15% to 50%. Deciduous trees are the best solution for shading because they lose their leaves in the winter allowing for the sun to penetrate and warm the building. Trees should be planted to the south of the building to "provide maximum summertime roof shading" (EERE, 1995). Refer to Figure 1.1.

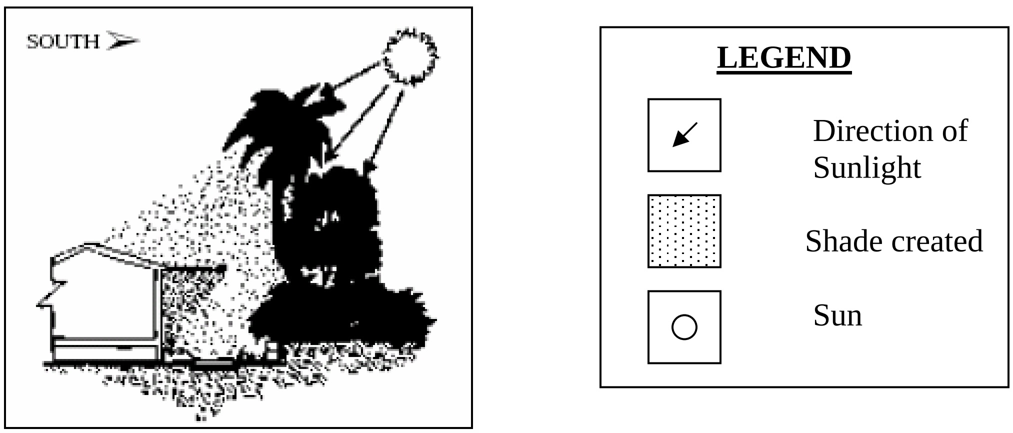


Figure 1.1 Shading Created By Proper Tree Placement

(Source: EERE, 1995)

Deciduous trees have high spreading crowns, therefore the shade can cover large areas of the roof and walls. Trees that have lower crowns are ideal for shading the lower afternoon sun. These trees should be planted on the west side of the building. Vines are another effective way of shading a building, even during their first growing season, and provide insulation in both summer and winter (EERE, 1995).

Shading the ground with trees, shrubs, and groundcover plants "can also shade the ground and pavement around the home. This reduces heat radiation and cools the air before it reaches the walls and windows" (EERE, 1995).

The best windbreakers "block wind close to the ground by using trees and shrubs that have low crowns" and "can cut fuel consumption by an average of 40%" (EERE, 1995). Evergreen trees and shrubs are often planted together to block wind from ground level to treetops. Evergreen trees, instead of merely blocking the wind, can deflect or lift the wind over the building. “A windbreak will reduce wind speed for a distance of as much as 30 times the windbreak’s height” (EERE, 1995). Refer to Figure 1.1 for a diagram of wind deflection. In Canadian winters when there is a cold wind, measures should be taken to prevent as much cold air blasting against the building as possible. In addition to having trees and shrubs as windbreakers, they can create dead air spaces between the building and the forage resulting in better insulation (one foot is ideal) (EREE, 1995).

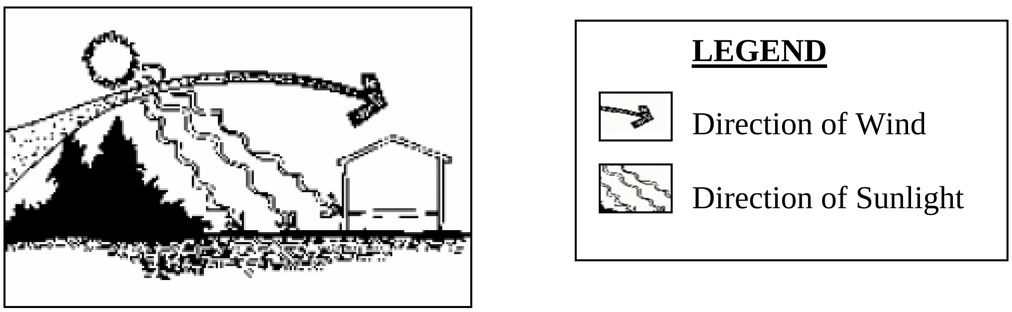


Figure 1.2 The Use of Coniferous Trees to Deflect a Cold Wind

(Source: EERE, 1995)

With proper landscaping, heating and cooling costs go down and energy efficiency goes up. By applying the above standards to ES2, the energy needed to heat/cool the building will be reduced making ES2 a little bit more sustainable and a little bit greener.

2.4 WINDOWS:

The windows in ES2 are double-paned with each pane separated by approximately two to three centimetres. According to The Consumer Guide to Home Energy Savings, the thickness of the air space between each glass pane has “a big effect in energy performance. A very thin air space does not insulate as well as a thicker air space due to the conductivity through that small space." If the air space is too wide convection loops between the layers of glazing occurs. Therefore, the air space should not go beyond one inch because it will not eliminate a further gain in energy performance (Consumer Guide to Home Energy Savings, 2004). "More efficient still are triple-pane windows, which seal two layers of gas within the frame" (This Old House, 2004), but the extra pane of glass is very thick, heavy, and costly. See Figure 2.0.

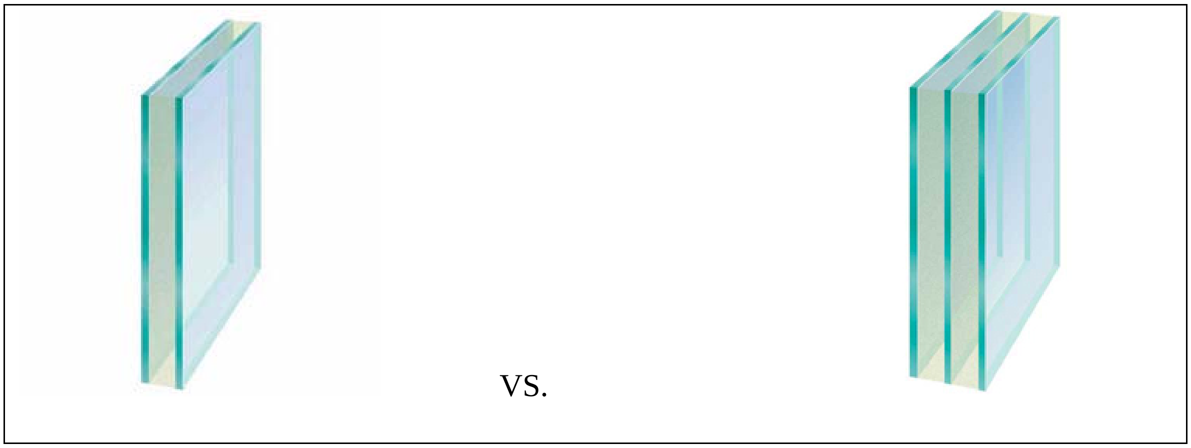


Figure 2.0 Double-Paned vs. Triple-Paned

Another alternative to increase the window efficiency is to substitute a low-conductivity gas fill, like argon or carbon dioxide, between the glass panes. "By substituting the air in a sealed insulated glass window for denser, lower conductivity gas heat loss can be reduced significantly" (Consumer Guide to Home Energy Savings, 2004). The gas is a low thermal conductor so it slows the passage of heat through the glass creating a more heat efficient window (This Old House, 2004).

Low emissivity (low-e) is an invisible layer of metallic oxide on the glass that reduces the amount of heat that passes through the glass. Low-E coatings can be tailored to let the sun's energy in or to block it out. "While low-E coatings add 10 to 15 percent to the cost of a window, research has shown that they cut energy expenditures by about

25 percent over plain insulated glass. Depending on the type of fuel used in a home, low-E windows can pay for themselves in 5 to 10 years" (This Old House, 2004).

By adding a second, third or even a forth layer of glazing energy efficiency can be increased. "Double glazing insulates almost twice as well as single glazing…adding a third or forth layer results in further improvement" (Consumer Guide to Home Energy Savings, 2004). Tinted glass coating also reduces heat gain through windows. They reduce solar heat gain without reducing visibility as much as older tinted glass and films. See figure 2.1 for an example of a product used for glazing. Dap's Glazing Compound is sold at any home repair store, such as Home Depot. One can of such a product costs only $6.19 making it an affordable product (Home Depot, 2004).

Figure 2.1 Dap 1 qt. Glazing Compound

The ideal window appears to be one made by Energy Star™. The savings from a typical single-paned window to an Energy Star™ window (which is at least double-paned and filled with argon) is 15% (Home Depot, 2004).

2.5 Insulation:

The insulation of the building should be of great concern to the retrofit of the ES 2. Environmentally conscience insulation has the potential to conserve money and produce a more environmentally sustainable building for work and study. That is why it is more economically and environmentally feasible to search for new products that could be used in a “Green Building” instead of using current products that may be more convenient to acquire, but in turn would also create environmental and economic problems in the future.

One such product is cellulose building thermal insulation.

> Cellulose building thermal insulation is a recycled product made from recovered newsprint and other paper (wood fiber) feedstocks. Paper, especially newsprint, represents one of the largest single components of the residential waste stream, and a major disposal problem for communities throughout the nation. Insulating a typical 1,500 square foot ranch-style home with cellulose insulation productively recycles as much newsprint as an individual will consume in 40 years (Lea 1996).

In addition to its recyclable properties, cellulose building material has energy conserving properties. In tests conducted by Oak Ridge National Laboratory of Oak Ridge Tennessee, results showed that the R-value, which is a numerical expression of the resistance to the flow of heat through a certain thickness of material, of the R-19 cellulose had a slight gain of about 10 percent. In comparison the R-value of tested mineral fiber insulation dropped (Lea, 1996). Both materials were tested under similar temperature conditions and the cellulose building material had an R-value gain, while the R-value of the mineral fiber insulation proceeded to drop (Lea, 1996). However, there are problems associated with installing cellulose. One such problem is that the cellulose can take anywhere from seventy-two hours to one year to dry. This depends on “the installation mix, moisture retarder, temperature, climate and when the drywall is installed” (Superseal Construction, 2004). The time problem could decrease the feasibility of using cellulose for insulation because it is suspected that the University would not want to wait a year to use a building.

Another environmentally friendly source of insulation is mineral wool, which, in comparison to fiberglass, uses 75% recovered materials versus the 20-25% recycled materials that is used by fiberglass. Mineral wool is comparable to cellulose insulation since it uses the same amount of recycled material. "The benefits from [Mineral Wool] insulation far outweigh the cost of production with a ratio of energy savings to energy investment of 12 to 1 per year. This means that for every Joule or Btu invested in the manufacture of mineral wool insulation, 12 Joules or Btus in energy saving are realized in every year of service." (NAIMA, 2004) Mineral wool can be divided into two types of insulation: slag wool, which is produced from wastes from an iron ore blast furnace, and rock wool, which is produced from produced from natural rocks, such as basalt and diabase (Winters, 1995). The more recyclable the material, the better it is for the University because it means that Waterloo will be able to purchase recycled materials cheaper and not have to continually purchase new products at great economic cost. As for polyisocyanurate, and phenolic foams, they both contain high amounts of "Chlorofluorocarbons, or CFCs, which are also greenhouse gases, were used until recently as blowing agents in extruded polystyrene, polyurethane, polyisocyanurate, and phenolic foam" (Winters, 1995). Thus, polyisocyanurate, and phenolic foams should not be used, and there should be a push by the University of Waterloo to incorporate CFC-free insulation in all buildings across campus, not just ES2. The following is a break down of different insulations used and how much product is recycled to produce insulations:

Material Type	Minimum Recycled Content Percent by Weight
Cellulose (loose fill and Spray on)	75% post consumer recycled material
Fiberglass	20-25% recycled culet (post-industrial or post-consumer glass
Mineral Wool	75% recovered material
Polyisocyanurate rigid foam	9% recovered material (polyol resincompontent)
Phenolic spray foam	5% recovered material (polyol resincontent)

Figure 3.0 EPA Recycled content Procurernent Guidelines
(Source: Winters, 1995)

As for the costs of different products, there are multiple variances between them. For any product, if the craftsmanship is poor than associated problems, like cellulose causing corrosion, could lead to a lower R-value and reduction of heat retaining properties of the insulation. Other factors affecting the price of insulation are how insulation is made, performance, fires or fire retardants, installation, air infiltration and moisture (Superseal Construction, 2004). All of these factors can potentially increase prices and make the installation of these insulations un-feasible. "The proper use of thermal [cellulose or mineral] insulation for new buildings as well as the retro-fitting of existing buildings increases their value. As such, these insulations represent a capital gain for the home or building owner" (NAIMA, 2004).

2.6 Thermal Mass:

Thermal masses are materials that absorb the energy from the sun to either cool or heat the area, such as cement, masonry, water, or brick. Water is an effective form of thermal mass, but it is difficult to incorporate into the functional design of the building (Sustainable Sources, 2004). During the winter, thermal mass will absorb heat during the day from exposure to the sun and the heat will be radiated from the thermal mass throughout the night (National Renewable Energy Laboratory, 2004). The opposite occurs during the summer. In most efficient designs, thermal mass is out of direct sunlight during the summer. Thermal mass absorbs heat from the room, thus, has a cooling effect on the area (National Renewable Energy Laboratory, 2004). ES2 is made primarily of interior brick walls and cement flooring, both of which are effective thermal mass materials. To maintain the effectiveness of these thermal masses they must be exposed to the living spaces and not covered by carpets or other similar materials (Iris Communications Inc, 1997). Another characteristic of thermal mass that will increase their effectiveness is their colour. Darker colours absorb more heat. Currently, the interior walls and floors of ES2 are very light colours. Their effectiveness to act as thermal masses will increase by darkening the colour of these materials. Any hollow cavities in thermal masses, such as those often found in cement blocks should be filled to increase the efficiency and absorbency of the thermal mass (Sustainable Sources, 2004).

2.7 Approaches to Passive Solar Design

The three approaches to passive solar design are direct gain, indirect gain, and isolated gain (Sustainable Sources, 2004). Direct Gain refers to the actual living space being the collector of the solar energy. In a direct gain system, the solar energy passes through a window where it will directly be in contact with the thermal mass materials

(Sustainable Sources, 2004). This form of solar design uses 60-75% of the sun's energy that strikes the windows.

Indirect gain occurs when thermal mass is located between direct solar energy and the area to be heated or cooled. The solar energy is transferred into the living space by means of conduction (Sustainable Sources, 2004). Approximately 30-45% of the solar energy that directly hits the windows is used in indirect gain systems (Sustainable Sources, 2004). Thermal storage walls, also known as Trombe Walls, are indirect forms of solar energy gain. Trombe walls are very thick and dark walls made of thermal mass materials that face south (National Renewable Energy Laboratory, 2004). The heat from the sun strikes a glass surface that is separated from the thermal mass by a few inches. This glass keeps the heat inside (National Renewable Energy Laboratory, 2004). The solar energy causes the thermal mass to increase in temperatures. Vents allow the passage of heat into the living space during the day (National Renewable Energy Laboratory, 2004). The vents are closed through the night and the wall cools as it radiates the heat absorbed throughout the day into the living space (National Renewable Energy Laboratory, 2004). Trombe walls operate under the same principles as a greenhouse. The building of a Trombe Wall, is possible due to brick walls already present, but may not be the most economical, practical situation as the walls of ES2 are already built, and renovations that would include the building of a Trombe Wall may require more output than the gain achieved from such renovations.

Isolated gain systems have the main parts of the system separated from the main living area required to be heated or cooled, such as a convective solar air collector and loop (Sustainable Source, 2004). The isolated system is the least efficient of the three approaches, making use of only 15-30% of the solar energy. The air collector is a system in which a collector obtains the solar energy, heating up the air inside. A passive form of this system requires the collector to be lower than the storage tank. As the air warms, it becomes lighter, and through convection travels to the storage tank where it can be released into other areas of the space through the opening of vents (Sustainable Sources. 2004). A non-passive system will function by the use of fans rather than relying upon the moving of the air itself (Sustainable Sources, 2004).

Similar isolated systems use water instead of air. In areas that freeze for long periods, such as Waterloo, indirect hot water systems are optimal. Indirect systems use fluids, often a mixture of glycol and water antifreeze. The heat is transferred from these fluids to the water in the storage tanks. The solar hot water systems can be both passive and mechanical. Mechanical systems rely on pumps and electricity, while passive systems rely on gravity instead. Passive systems are more reliable and contain no electrical components (Sustainable Sources, 2004).

Two types of passive solar water heating are the batch and thermosiphon systems. The batch system is the less costly and less complex of the two systems (Sustainable Sources, 2004). In a batch system, the collector is also the storage tank and water is moved throughout the system by the present water pressure in the building (Sustainable Sources, 2004). In a thermosiphon system the collector must be situated lower than the storage tank (Sustainable Sources, 2004). The hot water from the collector will move towards the top of the storage tank, while the colder water present in the storage tank will replace the hot water that left the collector. For sizing of these systems, the batch system is measured for use per person. It is suggested that the collector contains 20 gallons of water per person of the space, while the thermosiphon is sized relative to the size of the building and suggests a collector size of 20 square feet per person (Sustainable Sources, 2004). The chosen size will also vary depending on how much of an impact the system is desired to have. Diagrams of the batch and thermosiphon are shown below.

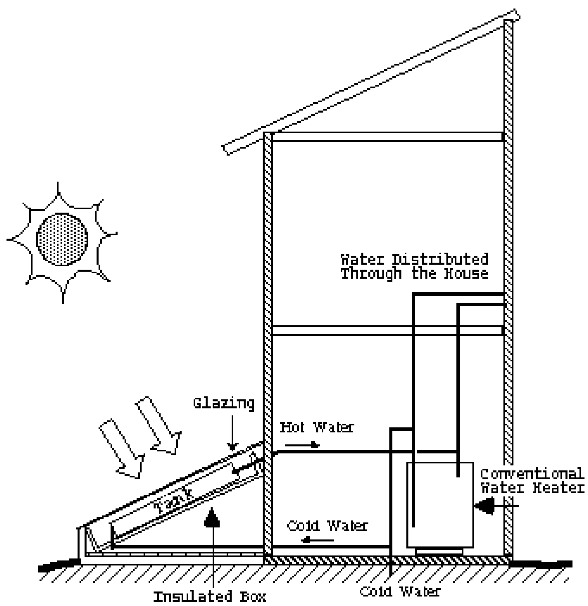


FIGURE 4.1 BATCH SOLAR WATER HEATING SYSTEM

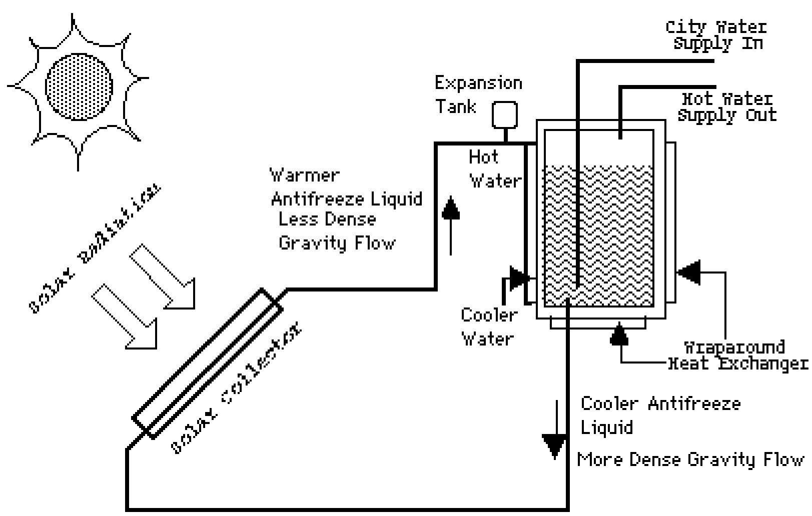


FIGURE 4.2 THERMOSIPHON SOLAR WATER HEATING SYSTEM

Passive solar water heaters are accepted by public opinion and the cost is satisfactory (Sustainable Sources, 2004). These systems are great additions to lowering heating costs, but are not meant to supply 100% of the required heat.

2.8 Passive Cooling:

The technology for passive solar cooling is not as developed as the technology for passive solar heating. Active solar cooling is also very costly, but there are several economical passive cooling methods (Natural Resources Canada, 2004). One of economical method that requires no energy and little maintenance is the use of natural ventilation. Natural ventilation can occur through operable windows. ES2 currently has some operable windows, but the installation of more will increase the natural ventilation cooling capabilities. Keeping the windows open during the night and closed during the day, or when it is warmer will further reduce cooling requirements. To enhance the possibilities of cooling through natural ventilation wing walls can be installed. Wing walls increase the air speed for ventilation purposes through operable windows (Sustainable Sources, 2004). Wing walls are simply constructed and very economical. They are solid panels placed perpendicularly beside the operable window. A top view diagram of a wing wall is shown in the figure below.

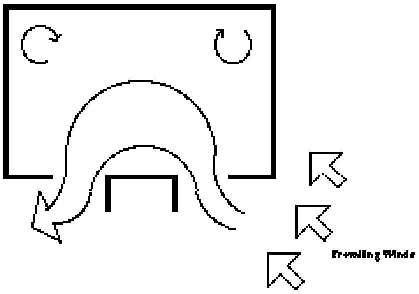


FIGURE 4.3 TOP VIEW DIAGRAM OF A WING WALL

2.9 ROOFING:

"To a certain measure, we have the opportunity to mitigate the developmental impacts of construction practices by replicating the environment that we have destroyed with the building footprint through the design of our rooftops" (Greenroofs.com, 2004). The roof of ES2 was taken into consideration because of the significant impact it has on heating and cooling processes. The roof has potential to either increase or decrease the building's level of heating and cooling efficiency. There are many ecological advantages to having a green area on a roof, however, there are great costs to putting in a green roof compared to putting in a roof that is not green. For example, "Taken together with the underlying waterproofing systems, an 'extensive' green roof installation in the US currently costs about $12 per square foot. The cost is roughly twice the cost of a premium roofing installation, without a green roof. It is about three times the cost of common low-cost 'built-up' or 'torch-down' roofing" (Rootscapes Inc, 2004). There are advantages to having a green roof for extended periods of time. For instance, "These typically [regular style roofing] require replacement or major repairs after about 15 years of service" (Rootscapes Inc, 2004).   Even though the installation of a green roof may be expensive, in the future, it will be less expensive overall because of the reduction of repairs and durability of the roof. Overtime, "overall building energy costs can be reduced due to the green roof's natural thermal insulation properties" (Greenroofs.com, 2004).

A very important part of a green roof is its ability to use heating or cooling sources to its advantage. According to literature presented by Erisco-Bauder Limited of England, "during the summer at high times of solar radiation, roof surface temperatures are much higher than the air temperatures, up to 80 degrees C" (Erisco-Bauder Limited, 1999). On clear winter nights when there are high levels of heat radiation directed upwards, the temperature of roofs can drop below that of the air and reach –20 degrees C (-4 degrees F)" (Erisco-Bauder Limited, 1999).This is also apparent in retarding heat transfer by advection and its interaction with the vegetation layer. "A very important function of the vegetation layer is to create a quiescent layer of air immediately above the roof surface. Without a green roof, wind (hot or cold) blows across the roof surface to either heat or chill it through the process of advection. The higher the air velocity the greater the thermal transfer. The concept is familiar to us as 'wind chill.' Buildings experience wind chill as well." (Rootscapes Inc, 2004)

Another effect of green roofs with regards to heating and cooling efficiency is the thermal mass effect. The effect, as was previously mentioned, allows green roofs to "absorb and store large amounts of heat. The effect is to create a 'buffer' against the daily fluctuation in temperature" (Rootscapes Inc, 2004). The effect is especially effective when there are high amounts of moisture. The heat transfer is at its most operable level when there is a large differential temperature between inside and outside. Yet, with the introduction of a green roof these extremes of temperature are reduced and/or eliminated. Thus, there are two results:

1) Heating or cooling equipment does not have to respond to the ‘peak’ loads at mid-day or mid-night, and
2) The overall heat transferred through the roof is reduced.

In addition “note that conventional insulation, while optimized for insulation value, has virtually no heat capacity and cannot function as a heat sink”. For this instance, “a green roof can work in combination with conventional insulation to provide a benefit greater than either used separately” (Rootscapes Inc, 2004).

This means that using green roofs to shield the roof from the effects of ultraviolet radiation, temperature extremes and mechanical damage can extend the life of the underlying roof waterproofing membranes. Therefore it is valid and feasible idea for the University to consider. All of these systems would greatly affect the heating and cooling in ES2 and the implementation of them would be beneficial to many ecological and economical facets of heating and cooling systems. With the increased amounts and accessibility of green buildings technology, the clarity of implementing green roofs to current roofing and the economical benefits that would follow after the installation of a green roof, would be, a favourable implementation for the university and green roofs should be incorporated into green building design.

3. Thermostats and Radiators:

3.1 Self Regulated Thermostats:

The ES2 building could benefit from the installation of self regulating thermostats. Individual thermostats could be implemented in every room, for better occupancy control. At this university the heating and cooling system is controlled by a main center, the general services complex (GSC), which controls all the heating and cooling operations on campus. The GSC is capable of overriding the individual thermostats in the rooms, but it is an advantage to have a regulated temperature to a certain extent. The new thermostats have many different economic and ecological gains. Programmable thermostats reduce energy waste because of its self regulation mechanism. When building occupancy is low, there is no need to use excess energy to heat or cool the space. A control system of this kind would ensure a reduction in heating and cooling costs. For example during the day in winter, heat levels can be at a comfortable level for occupants but during the night, when the building is not used, temperatures decrease automatically with the outside temperature and there would be no need for an individual to control it manually.

The Gasolec UK brand of self controlled thermostats involves an infrared heating system. The brand is able to fully modulate the heat and can operate at any level within its range. The Gasolec thermostats can regulate the temperature from a maximum to minimum by controlling the gas pressure put out by the system. Some different types of Gasolec heaters are, "automatic individual control: individual thermo-units automatically control the heat output of a heater (non-electrical). Non electrical zone controls are automatic zone controls without the use of an electrical thermostat. The zone control thermostat would be a good system for the ES2 building because it is has a high and low regulator that is adjustable to set high and low heat ranges. The zone controllers can be operated by any thermostat or central control that can send an electrically driven signal to the valve" (Gasolec UK, 2004).

The DSC power 832 thermostat control is a very different self controlling thermostat. It is an automatic or manual control of your heating, ventilation or air conditioning through a programmable thermostat or any touch-tone phone. The thermostat can be fully integrated into the security system for better convenience and the temperature can be lowered and increased by a telephone call (Security Masters-alarm and surveillance systems, 2004).

3.2 Types of Radiators:

Radiator design and type can have a lot to do with how much heat is put out and how it is circulated. There are two ways in which a radiator can emit heat. The first being convection which involves a small fin welded to the radiator panel in which heat is emitted and a small amount of heat is directly radiated by a steel panel; resulting in better efficiency and a more even heat distribution throughout the room. The second type is radiation which results in less efficient heating because of cold spots throughout the room (Plumbworld, 2004).

The different types of radiators that can be installed vary. Depending on the location of the radiator it might be best to install the specific one that meets the criteria of the room. Different types of radiators and their criteria include the steel panel convectors they are best used for domestic and commercial installations. They are the most common radiator but have an extra grill on the top. The Compact radiator is very similar to the steel panel convector but more aesthetically pleasing, it should be installed in a home. The integral radiator is has an electro zinc plate and has a powder coated panel that ensures high resistance to damp conditions, making it ideal for a washroom. The flat fronted radiator is a heavy duty plan radiator that can be placed in an area where damage or vandalism could occur. It is used most commonly in commercial applications (Plumbworld, 2004). The perimeter style radiator provides a blanket of radiant heat that can be attached to pipe covers on walls. The wall panel radiators are ideal for placement under a window. They can replace the old cast iron radiators and emit up to 1800btu (energy measurement) at 180F. The convective style emits up to 3400btu at 180F and can be perfect for glass walls (Runtal North American Inc., 2004).

"Many types of radiators are now used to heat the rooms of homes and buildings which have central stream or hot water boiler systems" (Colonial plumbing and heating supply, 2004). Different radiators, styles, and uses could be very beneficial to the ES2 building. We could determine the exact heat out put of a specific radiator and from there know where it should be installed. It is the same principal for the thermostats. If we could have a certain degree of individual regulating thermostats, then perhaps the rooms could be more comfortable for workers and energy loss could be reduced.

4. Fans & Ducts:

Fans and ducts play a very important role in an HVAC system with respects to controlling airflow and conserving energy. For large buildings such as ES 2, more than 25% of consumed energy is used for heating and cooling, and of this 25%, anywhere from 20-60% is used by fans and needed to transfer heated or cooled air/water from central heating and cooling plants to conditioned spaces. These two components are constantly running and using energy, and therefore need to be as efficient as possible (Platts Research and Consulting, 2004).

Fans and ducts are responsible for distributing hot and cold air as well as exchanging the air volume to best suit human health. Since they are running at all hours of the day, it makes these two features the best opportunity for energy efficiency retrofits. Fans can range from 40-80% efficiency and can come in many different layouts. They are low cost and come in wide availability of variable frequency drives (motors), in all horsepower ranges to make this technology an important part of most energy-efficiency upgrades (Platts Research and Consulting, 2004).

Two types of fans suited for practical use in an HVAC system are axial and centrifugal. Axial fans take the shape of a propeller, in which air is passed straight through the fan body. These fans are usually connected directly to their motors avoiding any loss associated with a drive belt. A central hub located on the fan also allows for the motor to fit conveniently behind the fan, yet makes the fan less efficient. Axial fans can be divided into three main categories: propeller fans, tube-axial fans, and vane-axial fans.

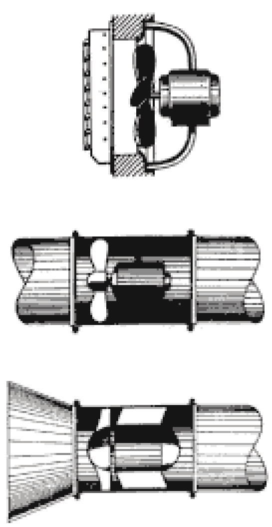


Figure 5.1 Types of axial fans. Top to bottom: the propeller, the tube-axial, and the vane

(Source: Platts Research and Consulting, 2004)

These three fans, the vane-axial is the most efficient for HVAC systems, consisting of straightening fins to covert circular, twisting air to get the fan moving. These fans have an efficiency rate above 80%, mainly due to the minimal direction change of air going through the fan. The pitch of axial fan blades can be easily adjustable or fixed. For most low-efficiency propeller fans and constant volume fans, the use of a fixed-pitch blade is desirable. Adjustable-pitch fans, on the other hand, allow the user to manually adjust the blade pitch and tune the flow, which is useful in safety factors without penalizing efficiency (Platts Research and Consulting, 2004).

Centrifugal fans, also called “squirrel cage” fans or possibly “utility” fans, are completely different, but still maintain a high efficiency rate. Instead of air passing straight through the fan, the air makes a 90^{o} turn and travels from the inlet to outlet as it is thrown from the blade tips (Figure 5.2). The centrifugal fan with the highest efficiency is that which uses airfoils or backward curved impeller blades, but straight radial fan blades are most commonly used in industry (Figure 5.3).

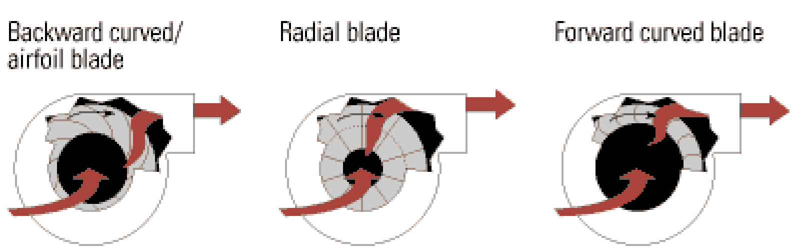
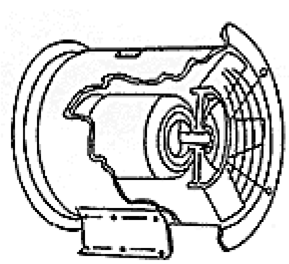
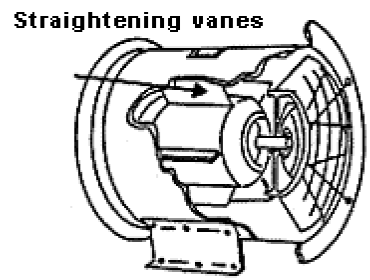


Figure 5.2 Centrifugal fan impeller blades -

Backward-curved airfoil impellers provide the highest efficiencies for centrifugal fans.

(Source: Platts Research and Consulting, 2004)

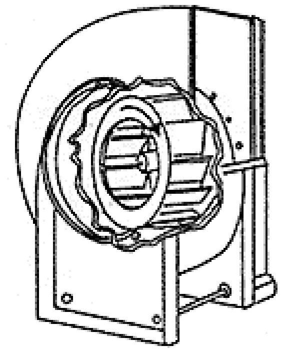


Figure A. Tube-axial fan.   Figure B. Vane-axial fan.   Figure C. Centrifugal fan.

Figure 5.3. - Fan performance curves for typical propeller, tube-axial, and centrifugal fans. All fans are from one manufacturer and have 1 1/2 horsepower motors. Note the air straightening vanes on the motor.

Centrifugal fans, often called "squirrel cage" fans, have an entirely different design. These fans operate on the principle of "throwing" air away from the blade tips. The blades can be forward curved, straight, or backward curved. (Figure 5.4)

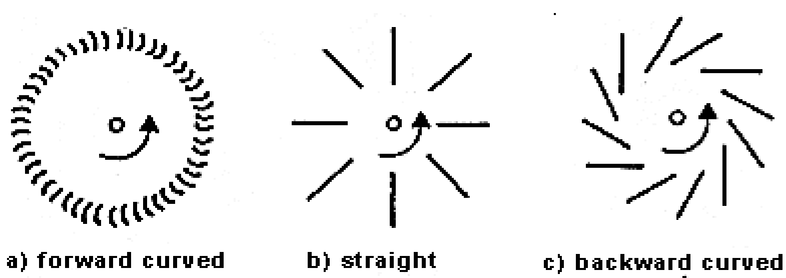


Figure 5.4. Schematic of centrifugal fan blade configurations.

An advantage to radial blades is that they allow the passing of foreign objects (particles in the air), but this does not apply to HVAC systems. Forward curved fan blades also have low efficiency, and are desirable for moving high volumes against low pressure i.e. window air conditioners (Platts Research and Consulting, 2004).

Though HVAC efficiency relies on the type of fan being used in a system, it also depends on the size. If a fan is too large or too small, it defeats the purpose of energy conservation. Taking into consideration the pressure, quantity of air delivered, horsepower required for air flow, and the actual fan efficiency, a fan size must be chosen correctly according to the size of the room the and HVAC system in order to conserve energy. Over working a fan, whether it's using more energy to run larger fans or to keep up with standards using smaller fans, is less efficient then properly sized fans that can supply adequate air (Supply House Times, 2004).

The most efficient and practical fans of HVAC systems would be a fixed pitch axial vane fans and centrifugal fans with backward curved impeller blades. These both need to be correctly sized to the space serviced and operate at speeds according to sufficient temperatures and pressures of the area.

4.1 Ductwork

Ductwork is a series of round or rectangular tubes, usually constructed of metal, which transports hot or cold air to and from a desired area. These tubes are usually located within floors, walls, and ceilings. Ductwork of an HVAC system is quite complex and varies between different buildings and HVAC systems. In general, there are many different ways of assembling ductwork. Each system is unique to the desired space, and manipulated and retrofitted according to the service required (U.S. Department of Energy, 1999). Though there are many different ways of assembling ductwork, there are simple ways in which to conserve energy. Making small changes such as: patching cracks and leaky joints, replacing broken fans, and introducing fiberglass duct liner and/or wrap, enormous amounts of energy can be conserved (CertainTeed Home Institute, 2004).

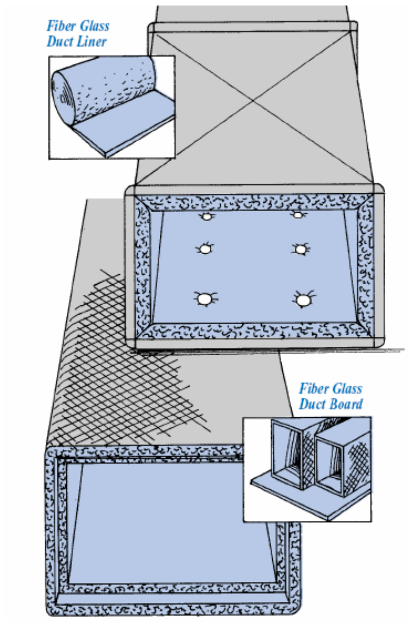


Figure 6.1.

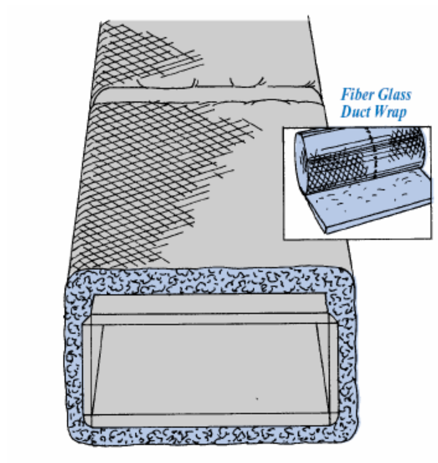


Figure 6.2.

(Source: University of Nebraska: NebGuide, 1996).

Two major energy losses from ductwork are from leaks and conduction. Air leakage is usually a result of poor joint work, or accidental holes and tears in the ductwork. Poor jointing is when two edges are connected together, and a small gap is unsealed between the overlapping metal (CertainTeed Home Institute, 2004). The gap is open to air leakage and must be patched to allow for proper flow and conservation. The same goes for leaks and holes within ductwork. When joints are not properly sealed, or cracks and holes are apparent, air within the tubing system will equalize pressure with the outside air, causing 10 – 20% of the leakage for the building (U.S. Department of Energy, 1999, p.6). When there is a hole or tear within the duct system, air will move from high pressure to low pressure; losing immense amounts of energy (U.S. Department of

Energy, 1999, p.3). Another way in which energy is lost is through conduction. Warm air inside the ducts conducts itself through the material, heating up the outside air. Even when ducts are inside the walls, they will conduct through the outside walls to the outside air, losing vast amounts of energy (U.S. Department of Energy, 1999, p.2).

Ways in which ductwork efficiency can be improved is by insulating tubes as well as checking that all fans are working properly. When fans stop working, duct pressures will equalize, losing energy to the outside air. Over the course of a heating season, the energy losses from ducts, when the fan is off, can be nearly as much as when the fan is turned on (U.S. Department of Energy, 1999, p.6). Insulation of ductwork is just as important as sealing leaks, and adds to the conservation of energy. Fiberglass can be used as an insulator for ductwork by applying it as an interior liner, or an exterior wrap (CertainTeed Home Institute, 2004, p.3). Fiberglass is usually manufactured into a rigid board format, which is then fabricated into the familiar duct shape. Fiberglass can also be cut and used as a bendable liner, insulating the inside of the ductwork using mechanical fasteners. In addition, fiberglass can be used in a blanket format in which it is wrapped around the outside of the ducts. “By nature, the material offers superior thermal efficiency, minimizing heating and cooling loss, while improving the efficiency of an HVAC system.” (CertainTeed Home Institute, 2004, p.3). Benefits to insulating ducts with fiberglass include: minimal air leakage, noise absorption, and low condensation. With ducts being properly wrapped with fiberglass it creates a sort of seal allowing minimal air leakage. The system reduces heat loss/gain and ensures that air in the ducts is transmitted to each room at the initial set temperature. The insulation also absorbs noise created by machinery, people, and airflow, allowing for a more sound proof comfortable setting reducing "cross talk" through vents. Also, by insulating and/or wrapping ducts, the amount of "sweat" coming off the metal from the condensation is reduced. The reduction in condensation will help to eliminate any drips and damage caused by rust (CertainTeed Home Institute, 2004, p.6).

Ductwork is very complicated, but making simple repairs such as the ones listed above can help to improve energy efficiency. It is said that making such repairs can reduce duct leakage to less than 3-5%, saving 15 – 20% on cooling and heating costs, in return paying for itself in less than 4 years (Florida Solar Energy Center, 2002, p.2).

5. Policy and Procedures:

On campus, Plant Operations have the ultimate control over what the heating/cooling systems are, how they work, and how they are regulated. "Where any modification or attachment to a building structure or services is required, a Work Request is to be issued to describe the work and show the estimate of cost involved" (Jack, 2004 (1)). Furthermore, no attachment or modification can occur "by persons other than Plant Operations personnel unless such personnel have been specifically authorized by any one of the Associate Provost, General Services & Finance, or delegate" (Jack, 2004 (1)). The above statements thereby prove that Plant Operations personnel have the control over whether or not modifications will occur.

However, if students want to make a suggestion about how to improve the heating/cooling system in ES2 they would have to go about it in a different way. To make a request to change to Class G policies, which are "university policies that concern the use of buildings, grounds and physical plant, the conduct of persons (students, staff, faculty, and visitors) on University premises, and other matters of general interest", a request can be made to the President by any member of the University community. "The initiation and development of Class G policies will be decided case by case by the President. When a Class G policy has been developed, it may be referred to any or all of the FRC [Faculty Relations Committee], SRC [Staff Relations Committee] and the Union/Management Committee for comment before being accepted or rejected by the President". One of the FRC's roles is "to provide a regular forum for discussion of matters of mutual interest to the Faculty Association and the University Administration" and one of the SRC's roles is "to forward any suggestions arising from discussions to the appropriate University deliberative body or administrative unit". (Jack, 2004 (2)).

Thus, the power of change lies in the hands of the President of the University and Plant Operations. To promote changes to the University of Waterloo, the propositions must be approved by the president of the University and Plant Operation. However, there are environmentally conscience group, such as Environment Resource Studies Student Association (ERSSA), that promote change through public education. Driving factors, such as ERSSA, have the power to change people's opinion but still the control over implementing change itself is in the hands of the President and Plant Operations.

6. Conclusions:

6.1 Recommendations

6.1.1 Windows

It is not plausible for economic reasons to replace all the windows in ES2 therefore, another layer of glazing is recommended to eliminate heat loss.

6.1.2 Landscaping:

ES2 already has landscaping to an extent therefore, the recommendations are to ensure that the landscaping has been done effectively, and if not, to improve upon it. ES2 already has vines on the walls of the north and south side sand as mentioned earlier; vines have insulating qualities.

In between the ES2 building and the PAS and Hagey Hall there is virtually no vegetation (trees or shrubs) to prevent wind blasting against the building or to provide any insulating values, or shade, etc. The majority of trees surrounding ES2 are Austrian Pines. As mentioned, the best type of tree to provide shade is a deciduous tree and not Austrian Pines (*Pinus nigra* A.). Therefore, it would be recommended that the Austrian Pines be replaced (they are dying away due to Diplodia Blight) with a native deciduous tree, like the sugar maple (*Acer saccharum* M.) (Farrar, 1995)

6.1.3. Insulation:

The best possible solution for the insulation would be to use a material that is highly recyclable, has a high R-value and also has a low cost. The most viable material that fits these standards is cellulose. Cellulose uses recycled materials, like newsprint and other waste paper and this would increase the environmental sustainability and reduce the cost because it uses recyclables instead of brand new materials. The application of this material to ES2 is very plausible and should be looked at by the administration as a feasibility solution for the retrofit of the building.

6.1.4 Passive Solar Design:

Passive solar design should take advantage of direct gain approaches as it is very economical and will use the highest percentage of sun's energy. Thermal masses such as cement and masonry should remain uncovered so they can absorb maximum heat. Making thermal masses darker colours will allow them to absorb more heat. The installation and effective use of operable windows would provide more ventilation; they should be open at night closed during the day. The installation of wing walls will enhance the ventilation, which is very economical. Curtains and overhangs should be properly installed as an economical means of heating and cooling. Maintaining an open interior design allows more efficient heat transfer throughout the rooms. The installation of a passive solar water heater will take pressure off of the main source of heating as well as providing a way of heating the area that uses no electricity. It would present a green/sustainable for ES2 image. It can be built at a small or large scale.

6.1.5 Fans & Ducts:

To recalculate the size of fans in relation to the servicing area, a proper fan size is needed to ensure that the necessary amounts of energy are being put out or conserved.

To re-service the ductwork, the replacing of any broken fans, and patching of holes is necessary. Insulating ductwork, using fiberglass insulation, ensures that minimal energy is lost through conduction to the outside air. It will also help patch up any accidental holes, prevent pressure loss and conserve energy. With reconstruction of new offices and or rooms, radiant floor heating should be introduced. Heating in this nature saves energy by having heat flow from the floor up instead of entering the area from the ceiling. Radiant floor heating entails a series of tubing under a floor in which hot water will flow through the tubing, conducting heat upwards through the floor. (Hackleman, 2004)

Heating a room in this nature is more uniform and is easier to produce desirable temperatures. Thermostats, using this method can be set 2-4 degrees lower than usual, which saves on energy outputs and costs (www.concretenetwork.com, 2004).

6.1.6 Thermostats and Radiators:

Having self-regulating thermostats in every room could be beneficial to the ES2 building because it would promote more efficient occupancy control. The new technology has many different economic and ecological gains and could further reduce the use of energy in the building. Self-regulating thermostats can cooperatively work with the present system to form a more effective method of heating and cooling. It might not be plausible to install such a complex thermostat system. As a result of an efficient system operating, the redesign of ES2 building would not be very economical or feasible. Many different types of radiators exist and the installation of effective radiators is a plausible idea. Radiators are easy to change, but depending on the type may be expensive. It would be more efficient if convection radiators replaced the old radiators as they heat the room by distributing the heat more evenly.

6.1.7 Roofing:

The roof has the potential to either increase or decrease the building's level of heating and cooling efficiency. The most plausible solution is to install a green roof because of the many environmental, economical, and social implications that it has. With the installation of a green roof, energy use of the building could be reduced because of effects like thermal mass and heat transfer by advection. These principles would allow ES2 to reduce energy costs, while having the same indoor weather as any other building would have. Also, the green roof would be a better long term investment than a traditional roof because of the durability and stability of the organic material.

6.2 Conclusion:

In conclusion, the consideration of these recommendations would lead to a more sustainable heating and cooling of ES2 it is necessary to consider many of the options above. Though they might not be feasible at 100% with different initiatives they might become more so.

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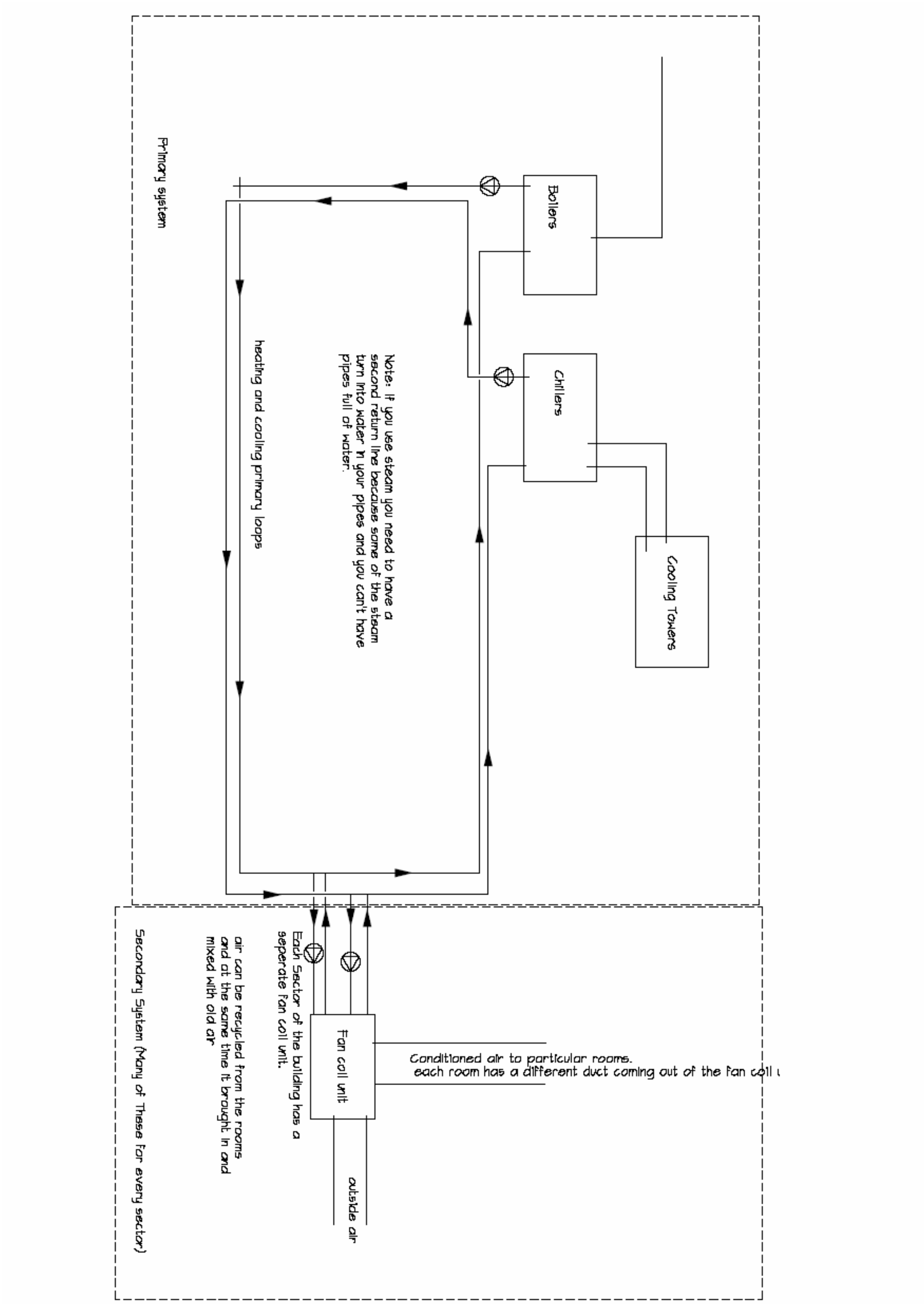
8. Appendices

8.1 Appendix A



Source: Nolan, P. (2004) Mechanical Engineer