MAPPING AND MODELLING URBAN SOLAR ENERGY POTENTIALS USING GEOSPACIAL DATA

A Case Study Of Ryerson University Campus

by

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Abstract

Mapping and Modelling Urban Solar Energy Potentials Using Geospacial Data

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Determining the solar energy potential on a surface depends on geographical location, prevailing meteorological conditions, size, shape and orientation of a surface. In urban areas shading is an important parameter, given the density of buildings and must be considered in an evaluation of available irradiation. This thesis develops an integrated workflow for modelling and mapping solar energy potentials in urban areas. This was accomplished through a case study of a typical large urban centre – The City of Toronto, using 3-D building models and selected software tools. The developed workflow was applied and successfully modelled the solar energy potential of buildings in the selected case study area. The results allowed for further characterization of the main factors affecting solar energy potentials on building surfaces in urban areas. This preliminary study indicates that, in comparison to HVAC systems and green roofs, shading may be a less important factor to consider when estimating solar energy potentials in some urban settings.

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List of Abbreviations

FIT	Feed-in-tariff
EROI	Energy return on investment
IESO	Independent Electricity Systems Operator
PV	Photovoltaic
IEA	International Energy Agency
OECD	Organization for Economic Cooperation and Development
SAA	Solar Access Analysis
IPSP	Integrated Power System Plan
OEB	Ontario Energy Board
OPA	Ontario Power Authority
SMAR	Supply Mix Advice Report
NGO's	Non-governmental organizations
MEI	Ministry of Energy and Infrastructure
PVPA	Photovoltaic Power System Programme
EPT	Energy Payback Time
ERF	Energy Return Factor
DEM	Digital elevation model
BIPV	Building integrated photovoltaic
ICUE	Irradiation mapping of complex urban environments
GIS	Geographical Information Systems
LIDAR	Light detection and ranging
HVAC	Heating ventilation and air conditioning
EEC	Energy efficiency and conservation

1. Introduction

The Province of Ontario is entering a new era in energy generation. The authorities involved in planning and decision making are being forced to rebuild key parts of the province's electricity infrastructure. This is a result of a bold decision to shutdown all coal fired generation in this province by 2014, and the unplanned end-of-life cycle of the entire nuclear fleet by 2025. A fleet that is responsible for supplying approximately half of the province's electricity supply. In addition, there is a growing demand and desire to build and potentially rely on renewable forms of energy supply.

The desire to replace older conventional forms of electricity with new renewables has been most recently expressed in the *Green Energy and Economy Act, 2009.* The most important aspect of this act is the creation of a feed-in-tariff (FIT) program that is expected to greatly increase renewable energy installations. Although renewables are perceived to be the solution to the province's energy issues, they pose a unique set of challenges and limitations. Transmission tends to become an issue with installations in remote places. The other major issue is reliability or consistency of supply. Except for bio-gas and hydro-dams, wind and solar only operate at certain times and in certain conditions. These limitations make solar and wind energy more costly to use because they do not provide a steady stream of electricity, which equals steady revenue for the owner.

There are options to minimize these limitations, specifically with solar. The simplest option is to locate solar arrays as close to demand and existing grids as possible, in particular the facades and rooftops of buildings in urban and suburban areas. In addition, it is possible to use advanced computer analysis techniques to maximize the output of any building related solar applications. These techniques can determine the best possible place to locate solar arrays on buildings and provide an estimation of the expected yearly and hourly electricity output.

In pursuing advanced computer analysis of building surfaces the information that would be generated can be organized into a powerful decision support tool. This tool would be able to indicate the best possible areas to locate solar arrays on buildings, which would maximize output. In addition, an estimation of yearly electricity output can be done and used in an energy return on investment (EROI) calculation to determine financial viability. In its most complete inception this tool would be able to aid in electricity management systems by providing hourly electricity estimations. With this data the Independent Electricity System Operator (IESO) could better manage the supply of renewable electricity to the grid.

The task of accurately estimating solar energy potential presents some difficulties due to the overall complexity of the process. The first issue is that of solar irradiation or insolation data. Unlike some weather data such as precipitation and wind, insolation data must be calculated using many individual variables and is specific to a geographical location. Also, on the data front accurate 3-D building data will be required as well as efficiency and size in m^2 for solar panel technologies.

Once all the appropriate data is attainted the next crucial component is to find and implement the proper software tools to achieve the research goal. This presents particular difficulty because there are many diverse tools and methods that could be implemented. In the broadest sense there is the option of using GIS, AutoCAD or customized software programs. The method chosen must also be able to perform the necessary analysis at the desired scale and level of accuracy. Therefore, much of this research will focus on finding the best software package or combination of software tools that can produce the desired outcome.

1.1. Scope

The scope of this thesis is limited to the evaluation and application of existing methods and tools designed to estimate solar energy potentials of buildings in urban regions. The literature review will be limited to a brief review of policy and institutional changes that have lead to the current desire to increase renewable supply. The remainder of the literature review will present and discuss the various methods available to complete the necessary analysis. Although, this thesis focuses on solar photovoltaic (PV) applications there will only be a brief discussion of solar PV technology in the discussion section. In addition, only one solar PV panel will be chosen for calculations and no comparisons of different panels will be made. However, it must be noted that the SAA results can be used for solar-thermal and solar daylighting.

1.2. Research Questions

What are the factors affecting or influencing the outcome of solar energy potentials in urban areas, and how can they be accounted for? What are the most suitable software tools to accomplish each objective set below? Using the chosen software tools determine the best possible areas on building rooftops and facades, within urban environments, to locate solar photovoltaic arrays. Finally, calculate an estimation of how much electricity could be generated from solar PV arrays if they were to be installed.

1.3. Research Objectives

1. Characterize factors that may limit solar PV installation on rooftops and facades.
2. Investigate existing methods and tools designed to estimate the solar energy potential on buildings to be implement in next steps.
3. Combine and evaluate tools into a workflow process and apply them to a 3-D model of buildings within a study area.
4. Provide an estimation of solar PV electricity output based on results from Objective 3.
5. Analyze how results from the workflow could inform or influence solar energy policy in urban areas.

1.4. Thesis Organization

The first chapter will outline the scope of this research, followed by the research question and objectives. The second chapter will present the literature review, which will begin with a more detailed review of the changes that have been made to energy law, policy and institutional structure. Following the discussion of law and policy will be a brief summary of a report published by the International Energy Agency (IEA) ranking select Organization for Economic Cooperation and Development (OECD) cities based on solar availability. The literature review will continue with a detailed discussion of all the possible methods for conducting computer aided solar energy modeling.

Following the literature review, the chosen method and accompanying workflow will be presented, including a detailed discussion of each step outlined in the workflow. In the Results section a discussion of the results shown by the solar access analysis or (SAA) for each building analyzed will be discussed. A summary sheet for each building, shown in Appendix D, will present the SAA results, satellite image and 3-D building model. At the end of this section a summary table for rooftops and facades will be presented. The last section will discuss the overall results and compare them with total building electricity consumption for the entire study areas. This will provide some perspective of the effect solar PV generation would have based on the computer analysis of the study area.

2. Background and Literature Review

This section will begin with a brief discussion of the main legislative documents that govern energy policy in the province of Ontario and recent changes that have been made. In addition, the main planning documents the Integrated Power System Plan (IPSP) and Supply Mix Directives will be presented. This information is necessary to frame the remaining sections which present the energy related challenges currently being faced by the Ontario Government and associated institutions. A separate section will discuss the most recent solution passed by the Government, that of the *Green Energy and Economy Act, 2009* and the new feed-in-tariff (FIT) program designed to increase renewable supply. The last section related to background information presents a study of the solar potential of Canadian cities prepared by the International Energy Agency (IEA).

2.1.Supply Mix Directives and the Integrated Power System Plan

Significant changes have been made to energy law, policy, and institutional structure in recent years. On the legislative front, a 2004 amendment to the *Electricity Act, 1998* referred to as the *Electricity Restructuring Act* was designed to " encourage new electricity supply, energy conservation and stabilization of prices at a level reflecting true cost pricing" (OEB, 2008). The amendment and the original act governs all stakeholders, institutions, regulations and policy planning related to or involved with energy generation in the province. The general purpose of this act was to "ensure the adequacy, safety, sustainability and reliability of electricity supply in Ontario" (Electricity Act, 1998, Sec. 1(a)). In addition, this legislation created a new entity under the Ontario Energy Board (OEB) called the Ontario Power Authority or OPA.

The *2004 Electricity Restructuring Act* mandated the Ontario Power Authority to prepare a planning document that presented a strategy for meeting electricity demand over a 25-year timeframe called the Integrated Power System Plan (IPSP). This document was to be updated periodically or upon the submission of new Supply Mix Directives issues by the Minister of Energy and Infrastructure (Electricity Act, 1998, Sec. 1(a)). The Directives are a set of guidelines indicating what generation option and technologies the government would like to be included in the IPSP. It is important to note that the Minister does seek the advice of the OEB and OPA on what to include in the Directives in a document called the Supply Mix Advice Report indicating what the OPA feels are the most viable options over the next 25-years. However, the Minister still has discretion over the Directives issued (OPA, 2006).

This dichotomy has been expressed recently in 2008 when the new Minister of Energy and Infrastructure, George Smitherman, amended the 2006 Directives on his own accord. The original 2006 Directives were based on the only Supply Mix Advice Report (SMAR) issued one year prior (OPA, 2005). No SMAR was published by the OPA prior to the 2008 Amendments. Nevertheless, given all this change over the past few years, Ontario has managed to improve its energy planning processes and the overall operation of the electricity grid (Winfield, *et al.*, 2004).

The amendments made to the Supply Mix Directives and issued on September 17, 2008 only addressed environmental sustainability aspects of electricity supply and distribution. A few of the more pertinent amendments to this research call for increased renewable generation, decentralization of supply, increased conservation and efficiency measures, and quicker adoption of Smart Meters (Directives, 2008). The OPA responded to the amendments on March 12, 2009, stating that a revised version of the IPSP would be submitted to the OEB for review on March 17, 2009 (OPA, 2009).

These new Directives are a significant departure from the initial set of Directives issues in 2006. The 2006 Directives were the first following the passing of the 2004 *Electricity Restructuring Act*. They established a base case scenario with the aim of eliminating coal, maintaining and/or replacing the current nuclear fleet, and meeting the remainder of demand, approximately half, through renewables, conservation and efficiency measures (Simtherman, 2008).

The IPSP that resulted, from the 2006 Directives, was reliant on nuclear energy for baseload providing roughly 50% of the provinces electricity. However, in recent events the government has begun to question this approach. Much of this change was due to the financial burden of constructing, or refurbishing nuclear facilities; but there is also resistance from many NGO's such as the Ontario Clean Air Alliance and The Pembina Institute who criticized the government for not including more renewable generation (OCAA, 2009). In particular, the Pembina Institute published a report called *Renewable is Doable*, which outlined, in detail exactly how the government could supply the provinces needs with renewables (Peters, *et al., 2007).*

With the recent interest in renewable energy generation and general sustainability, Ontario is poised to make significant advancements in renewable generation and smart grid technology. This change, however, could not have come at a better time. In reality the province is facing some hard deadlines and the elimination of the bulk of its generation capacity by the year

2025. This reality was partly responsible for the legislative, and institutional changes that lead to the creation of the IPSP era (Winfield, 2006).

2.2. Supply and Demand Balance in Ontario

There is a looming supply and demand deficit predicted for the province. Not unique to Ontario but a problem the government is trying to solve. The permanent retirement of its aging nuclear fleet by 2025 and all coal fired generation facilities by 2014 together eliminating almost sixty percent of Ontario's generating capacity (OPA, IPSP 2008). The government is keen on

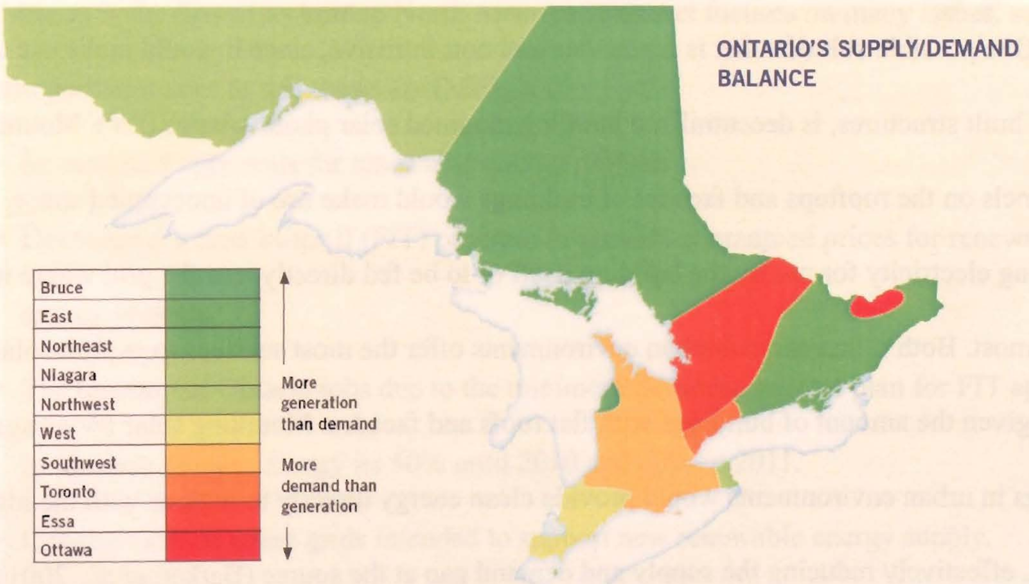


Figure 1: 2009 IESO Supply and Demand Balance in Ontario

bolstering renewable generation, in particular with large centralized wind and solar farms (*Green Energy Act, 2009*). This approach has had both positive and negative environmental and economic issues. The main problem is that is does not produce electricity where it is needed most, in densely populated urban areas (Soloman, 2009). In its annual report, the (IESO) showed that the largest energy deficits are in places like Toronto and Ottawa, due to their higher demand and distance from centralized generation facilities, see Figure 1 (IESO, 2008).

There are many solutions to this imbalance, most of which include greater conservation efforts and locating supply closer to these areas. Conservation is important and should be feverishly pursued as part of an effective energy plan. The idea of locating supply closer to demand presents some issues. There are many reasons why it is not already done, one being that people generally do not like to live near large generation facilities. Also, there is a simple issue of land use. Any large conventional (fossil fuel or nuclear) facility requires large amounts of land, which is at a premium in city centers.

One possible solution that is renewable and non-intrusive, since it would make use of existing built structures, is decentralized building mounted solar photovoltaics (PV). Mounting solar panels on the rooftops and facades of buildings would make use of unoccupied space, generating electricity for use by the building itself or to be fed directly into the grid where it is needed most. Both urban and suburban environments offer the most surfaces to exploit solar energy, given the amount of buildings with flat roofs and facades. Mounting solar PV arrays on buildings in urban environments would provide clean energy directly to regions with the highest demand, effectively reducing the supply and demand gap at the source (Barker, *et al.,* 2001).

In the 2009 Reliability Outlook the IESO altered its forecasts for electricity demand growth over the next 20-years. The OPA and IESO have effectively eliminated almost 8, 000 MW of projected demand from its forecasts (IESO, 2009). This shift is based on the fact that actual demand growth has slowed and is projected to fall further. The other factor affecting this is the fact that the province has been meeting its conservation and renewable generation goals. This is a major shift from the previous Reliability Outlook's and general energy policy in the province which expected steady growth and falling supply (IESO, 2008).

This amounts to a newfound sense that it is possible to meet energy demand over the next 20-years without having to build large centralized facilities, specifically nuclear. In addition, the new *Green Energy Act, 2009* and feed-in-tariff program have made renewables and conservation more financially attractive.

2.3. The Green Energy Act and FIT

On May 14, 2009, the Ontario Legislature passed the *Green Energy Act, 2009*. This piece of legislation is the first of its kind in North America. This Act focuses on many issues, some of the more pertinent ones to this thesis are (MEI, 2009):

- Streamlined approvals for renewable energy projects,
- Developing a feed-in-tariff (FIT) program to provide guaranteed prices for renewable energy projects,
- The creation of Ontario jobs due to the minimum domestic content plan for FIT approval. In the case of solar energy its 50% until 2010 and 60% in 2011.
- Development of smart grids intended to support new renewable energy supply.

With the establishment of a Feed-in-Tariff program, offered through the OPA, the province has made substantial progress and is joining the ranks of the renewable energy elite such as Germany, Spain, California, and Italy, which have FIT programs and have seen a rise in renewable generation capacity (Polo, *et al.*, 2009).

The FIT program exists in two-forms: 1) micro-FIT for small-scale and residential installations under 10 kW and 2) FIT for larger industrial installations. The micro-FIT program offers an incentive payment of 80.2¢/kWh of electricity feed back into the grid. For projects over 10 kW the pricing schedule depends on the size of the array. This pricing is designed to cover capital cost for installation and operating and maintenance costs (MEI, 2009). Some have criticized this strategy as a very expensive way to promote increased installation of renewable generation (Solomon, 2009). Although there is some truth to this claim, the OPA does state that pricing schedules are up for review approximately every two years. If FIT is as successful as predicted it's costs could drop rather quickly allowing the OPA to reduce payback, and avert financial risk in the long term.

2.4. The Solar Option in Canada

Although it is possible to install solar arrays on buildings in urban regions to reduce the supply and demand gap, the question remains: does Ontario receive enough sunlight throughout

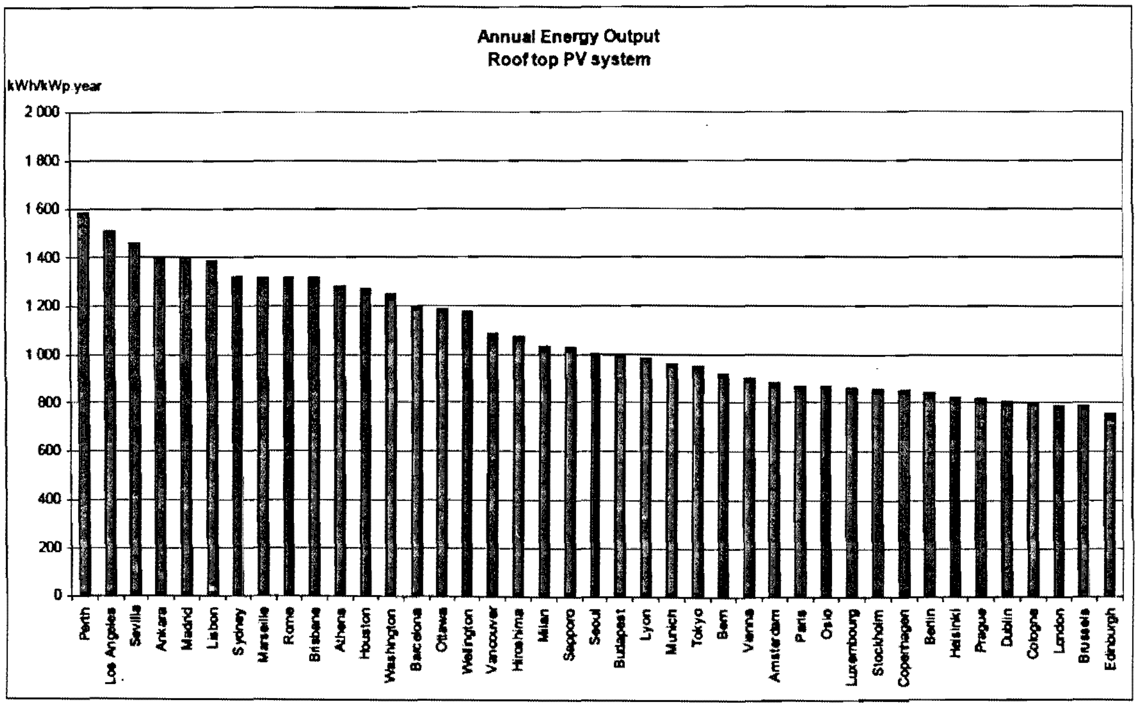


Figure 2: IEA OECD Summary of Annual Energy Output

the year to make solar technically and economically feasible? The answer to this question can be found in a 2006 report published by the International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS) (Gaiddon & Jedliczka, 2006). The report looked at the solar access of major cities within OECD countries, ranking them against each other. Two Canadian cities were chosen: Ottawa and Vancouver, which both receive surprisingly high amount of sun light compared to other cities such as Barcelona, Spain; Houston, Texas and Milan, Italy (see Figure 2).

This analysis is based on life-cycle energy requirements including the manufacturing of the panels, mounting equipment and the eventual dismantling and recycling of each panel (Gaiddon & Jedliczka, 2006). The results of this study are presented as cumulative net energy production showing the amount of years it takes a panel to recoup initial energy demands. This is based on two measures: 1) Energy Payback Time (EPT) (years), and 2) Energy Return Factor (ERF) (number of times). Ottawa is estimated to have an EPT of 2.1 years for rooftops with an ERF of 13.1 times (Gaiddon & Jedliczka, 2006). The results of this report indicate that comparatively Canadian cities are good places to install PV arrays, since the payback period would only be around 2 years based on the overall solar resources. Meaning that it would take 2.1 years for a solar panel to produce as much energy as it took to make the panel itself.

This report offers fair grounds for pursuing this research, since it establishes that Canadian cities do receive enough solar energy to support solar PV installations. The top three countries with the most solar generation capacity: Spain, Germany and Japan; in comparison, have much lower insolation values compared to Canada. Only Spain has significantly more, however, it should be noted that Barcelona receives only slightly more sunlight than Ottawa.

2.5.Literature Review of Solar Energy Potential Modeling

There are three main options or methods discussed in the literature to estimate the solar energy potential of buildings in urban environments. The first site-by-site field assessment is currently the method of choice. It may be done at the beginning of a process to gain measurements and for visual inspection of a site or at the end of a solar site assessment, to verify computer based analysis. The second and third options both involve computer analysis of an environment. One method involves using 3-D building models and various software tools to analyze solar radiation of building surfaces or entire regions. This method can offer very detailed and useful results to be used in a decision making process or to aid in site assessments. The final option involves the use of GIS software tools to analyze a building or regions solar radiation in much the same way as the second option.

2.5.1. Site-by-site field assessment

This method is the most basic of the three options and is commonly used for that reason. The only difference in this method is that no computer analysis of the site is done. Instead surveyors and engineers would go to a site of interest and visually inspect it and take measurements to be used in calculation and estimations. Although this can be effective it is time consuming and does not allow for analysis of large areas or many surfaces in a timely manner. In addition it is not always easy to determine the effects of shadowing simply by visiting a potential site of installation. Site-by-site field assessment is a necessary step but should be supplemented by some form of initial assessment and instead used as a final step to verify analysis and calculations.

2.5.2. 3-D computer modeling

Three dimensional computer modeling using scaled digital representations of buildings and urban regions can allow for detailed solar irradiation analysis. The main strength of this approach is that it is based on well established and powerful computer software. There are two main options in terms of software tools for this approach, depending on the overall goal of the research. If the research goal is to validate or develop a new algorithm then the use of command-line driven programs that offers complete control over parameters and algorithm execution is the best option. The other option is to use a slightly more mainstream software program with a well developed user interface and predefined analysis tools.

For those that use a command-line driven approach, a UNIX based program called RADIANCE is often the program of choice. RADIANCE is open source software developed by researchers at the University of Berkley and is free for download. It is designed to be a research tool and does not offer a user interface. It requires expert programming skills to operate; however, once programmed it can handle highly complex 3-D building models offering many analysis functions and yielding highly accurate and detailed results. A major strength of RADIANCE and 3-D modeling is the ability to handle and use shadows in solar analysis calculations (Compangnon, 2004).

In an article titled *Solar and daylight availability in the urban fabric*, Compangnon (2004) investigates ways to measure solar penetration in the urban fabric, or simply the amount of sunlight that reaches building surfaces. This is important because of the density or proximity of one building to another in urban areas, and the resulting shadows cast, blocking sunlight on adjacent surfaces. Compangnon uses RADIANCE for lighting simulations and a stereographic projection for sky factor and shading. The stereographic projection is a disk representing 360° of the sky separated into 4330 squares. When computed squares are white indicating no obstructions in that space, others will be either shaded in grey indicating a degree of overshadowing or black meaning complete obstructions. The shaded and white squares make up the sky factor representing the portion of the sky that a surface has access to. The author uses a 3-D building model overlaid on a digital elevation model (DEM) of the area and ran a full simulation to determine insolation values. In combination with the stereographic calculation the author is able to determine the specific areas on each buildings surfaces that receives more than a threshold of 800 kWh/m^2/year .

A similar effort was done by Mardaljevic and Rylatt (2003), using an image-based approach to map solar irradiation over complex urban environments or city centers. Their goal was to create a detailed model that could be used as a decision making tool for estimating PV installation on buildings or as building integrated PV (BIPV). The method is not new, yet based on three common steps to 3-D solar modeling. The use of a sky factor and integrated shading calculation is the main limiting factor in the overall calculation. The authors chose to create a calculation that combines both direct and diffuse solar components with an overcast sky model. The rendering and visualization was done using RADIENCE and is referred to by the authors as an irradiation mapping of complex urban environments or ICUE. Since one of the goals of this method is to make the ICUE data available, the authors chose to use an end-user GIS application similar to Google maps. The data can be accessed through a simple search function using ICUE to present information and visualizations to the end-user .

One of the many strengths of this approach is the use of sky view and shading calculations. The most common method involves the use of a shading mask, which is a 2-D representation of a 360° sky split into a grid. The benefit of this approach is that each shading mask contains all the necessary information in terms of solar access any one surface receives. Once a mask is calculated it can be saved and used as needed for further analysis. In addition, once one is familiar with shading masks it is often possible to determine, from the mask alone, whether a surface will be suitable for solar applications. In essence this method although complex itself simplifies the overall process (Mardaljevic, 2000).

Although, Mardaljevic and Rylatt, and Compagnon all present novel methods and overall process for irradiation mapping of complex environments they only provide equation and algorithms and not a completed software tool. Essentially, these authors explain how to accomplish the task but leave the development and application of the software tools to other researchers. The other issue is that since RADIANCE is used for the computation and visualization, one would have to reprogram the simulation line-by-line using the authors' algorithms in hopes of replicating their results. This may be useful to other researchers, but it is of no use to an average end-user or decision maker.

2.5.3. Geographical Information Systems (GIS)

GIS is a commonly used tool for mapping and surface analysis. Many journal articles employ GIS tools to accomplish some form of solar energy analysis. Some software packages contain basic solar analysis tools that yield a uniform insolation value for an entire geographical area. GIS is able to accommodate digital elevation models, which can greatly affect solar access in mountainous regions. Aerial photos of a study area can be used to measure rooftop surface areas for the identification of potential sites to locate solar arrays. If LIDAR data is available accurate 3-D digital surface models can be generated, and solar analyses can be conducted on surfaces. However, this type of data is not readily available for many regions and does require a fair amount of technical skill to use in a GIS environment.

Four articles of particular interest and relevance to this study are reviewed here. The first article is written by Arboit et al. (2008), entitled *Assessing the solar potential of low-density urban environment in Andean cites with desert climates: the case of the city of Mendoza, in Argentina.* Arboit et al. looks at the relationship between urban morphology and solar access in low-density urban environments and low-rise buildings. This is not a limitation of the model but is a reflection of the predominate type of architecture in Mendoza. The authors, however, are only interested in passive solar space heating with potential collection areas limited to vertical north-facing walls (+/- 15°).

The first major issue identified, is the shading of trees on roof space, given the low-rise architecture and fairly tall trees in Meondoza. To address this Arboit et al. have devised a detailed method to account for several features of the urban forest. These features are designed to determine the impact, on solar access, of tree canopies. The features assessed are as follows:

- Tree species
- Size
- Shape
- Deciduous or coniferous
- Solar permeability of crown during seasons
- Degree of completion of the tree stock around each city block

The information required to assess tree canopies and individual buildings is attained from: satellite images, orthophotos, government property data maps, cadastre maps and extensive field study

Thirty two sample groups were chosen which contain many individual units or dwellings. Each sample group acts as a single unit or structure for analysis but in reality consists of many individual buildings. In choosing the 32 groups the variables that were considered are

- Shape of city block expressed in rectangular units
- Orientation of city blocks - angle relative to north
- Street width
- Urban tree structure categorized as magnitude 1 to 5
- Solar permeability of tree canopy, represented as a percentage
- Completion of canopy, represented as percentage of existing verses total possible

The authors have chosen to use a standard insolation measurement representing yearly mean horizontal global solar radiation (18.06 $MJ/m^2/day$), applied to various other measurements accounting for obstructions and shading. This is the most basic method to measure solar insolation and the most limited in terms of time-steps. When using a static insolation value there is no option to assess potentials in real-time or in a specific time interval (15 min, 30 min, 1 hr). This flexibly is crucial to determine how long and at what time of day a surface is shaded. For example, if a rooftop is shaded in the morning and evening but is not during the day, when insolation is the strongest, it may still be feasible for solar applications. Furthermore, this model only uses direct beam radiation on a clear-sky days, instead of both direct and diffuse with and without a clearness index, to be more representative of actually insolation over a year.

Simulation were run on the 21^{st} day of the month, from April to August for a duration of 5 hours (9:30 am to 2:30 pm), which is considered the most intense insolation period. The authors justify this short simulation period by arguing that June 21^{st} is the day of the year with the lowest value of solar altitude, yielding the greatest level of solar masking (least amount of sun), and providing values for the day with the lowest solar radiation.

The second article of interest is by Hofierka & Kanuk (2009), entitled *Assessment of photovoltaic potential in urban areas using open-source solar radiation tools*. The authors choose to assess photovoltaic potentials in urban areas using an open-source solar radiation tools called *r.sun* and PVGIS. This model also uses 3-D building models and terrain mapping within a GIS environment.

The *r.sun* module is part of GRASS GIS an open source software, which the authors have chosen to use because of its ability to run *r.sun* and *r.horizon*. The *r.sun* module is raster based and allows for spatially variable input and output data. It estimates direct beam, diffuse and reflected insolation components, clear-sky and real-sky (clearness index) for horizontal or inclined surfaces. This means that the output of the model, as far as insolation is concerned, is very accurate and representative of real-world PV outputs. The authors employed a digital elevation model to account for sky obstruction on local terrain through the *r.horizon* module, which allows for faster processing.

The *r.sun* module operates in 2 modes:

1. Instantaneous mode - calculates raster-based maps of insolation (W/m^2) and incident angle of solar rays.

2. Raster based maps of daily total insolation and duration of irradiation computed at a user-selected time step.

This model does use a 3-D building model, which is generated with orthophotos, building footprints, field mapping and a digital surface model that includes buildings. The data needed and collected for the 3-D maps are:

- Orthophotos
- Digital Elevation Model
- Vectorized building footprints
- Building height and roof type, inclination and available roof area mapped using laser distance device

The last method of using laser distance devices is rather time consuming and expensive. Although it provides high quality data for the model, the level of field work required to gain the data almost defeats the purpose of running a computer simulation. Furthermore, in most cities around the world planning offices possess high-quality 3-D building maps that can be attained for a nominal fee or for free.

The authors choose to take the root of defining four urban zones based on morphology and function (form and function): 1) Residential houses, 2) Blocks of flats, 3) Industrial areas, and 4) other (schools, garages, sport and entertainment halls) . This is a useful and logical way of assessing large city landscapes and organizing data tables for analysis.

The third article by Seong et al. (2006), titled *HELIOS: Solar rights analysis system for apartment buildings*, implementing purpose built solar analysis modules, 3-D building models and GIS. The model they have created is referred to as HELIOS and has been designed for the government to assess solar rights or accessibility of buildings. This model, however, goes one step further than others and is interested in the solar accessibility of individual apartments, condo units and office spaces within a single building.

For the solar analysis of buildings a program called WALDRAM was created, which projects the sun path using vertical axis altitude and horizontal axis-azimuth (angle). This program is its own entity of HELIOS that is designed to analyze whether each point of interest (building, office, or apartment) is shaded from the sun on a time-step of a minute. A visualization is then produced using the building geometry data based on a 3D model.

Each building has a geometry classification of: UNIT, ROOF, FLOOR, BUILDING. This is a very useful breakdown to attain specific solar access of a building ranging from the roof, facades, and even each window. In order to attain this level of information WALDRAM uses survey data-sets that include: points, altitude, longitude, date and time.

HELIOS is designed as a modular program with each module corresponding to functional steps of the process:

- Pre-processing - input data management
- Core-processing - solar analysis (WALDRAM)
- Post processing - report generation and analysis
- Library management - data handling

HELIOS is a highly customized, purpose built group of programs designed to fulfill solar right assessment, which is required by law in South Korea. Nevertheless, it is a novel approach and provides a high level of flexibility and analysis. However, none of the programs or scripts is available for downloading and use. The authors do provide all the necessary equations for WALDRAM and schemas for data structure needed to replicate HELIOS.

In the last journal article by Izquierdo et al. (2008), entitled *A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations,* a methodology for estimating roof area availability for solar applications, excluding facades is presented. This is accomplished with GIS software and linux-shell scripts for data processing, and a Google Earth plug-in for Spanish cadastre to attain urban maps.

The authors refer to this model as a hierarchical potential methodology, which includes three steps:

1. **Physical potential or gross solar insolation** is calculated by using monthly extraterrestrial solar radiation, and a monthly clearness index based on metrological data for specific location. This data is then run through the Kriging tool in ArcGIS on a 200m x 200m grid yielding a solar insolation map to base calculations on. This step also includes the use of a digital terrain model to account for shadows, however, it is not clear if this is considered the building model.
2. **Geographic potential** assess the available surfaces on roofs and corresponding area in meters square. Available areas are estimated through the use of a formula to account for various factors that are required to make an accurate assessment. The factors are as follows:
   - Built-up area (A_b) : surface area occupied by buildings
   - Roof area (A_r) : area within built up area that is roofing (this is the building footprint either attained directly from a data source or through the footprint tool in ArcGIS)
   - Available roof area (A_a) : roof area that can be used for solar applications

- Available roof area is attained by applying restrictions defined as:
  - Void fraction coefficient (C_v) : to consider voids and recesses in buildings
  - Shadowing coefficient (C_s) : accounts for shadows generated by other buildings, objects, or by roof configurations (requires 3-D digital surface/building model)
  - Facility coefficient (C_f) : excludes surfaces in use

These factors are then combined into the following equation: $A_a = A_r C_s C_f = A_b C_v C_s C_f$.

3. **Technical potential** is the final calculations which consider three aspects: 1) radiation over titled surfaces and the computation of direct, diffuse and ground-reflected radiation, 2) space needed between modules to avoid shadowing, especially during winter, and 3) PV model efficiency.

GIS has been demonstrated as a functional solar analysis tool in the journal articles discussed above. However, all authors were forced to create custom solar analysis tools that are not readily available. Also, none of the studies found was able to easily account for overshadowing from adjacent structures. Most study areas where in low rise, uniform areas where overshadowing was not a major concern. Overall there was a lack of well developed solar analysis tools in GIS environments. In addition, there are issues with the lack of capabilities of GIS software programs to accommodate complex 3-D building data.

3. Methods and Procedural Workflow

This chapter outlines the steps and guidelines that will be followed to achieve each objective and the overall research objectives. The first section will discuss the general criteria that will be used to select a software package. Also, the procedural workflow will be presented in this chapter and discussed in detail focusing on the building model and data.

3.1. General Criteria for Software Selection

Before investigating any methods and software tools to accomplish the above research objective it is important to identify the criteria to be incorporated into the overall model workflow. This will help with the selection of an overall method and specific software tools, since any chosen must be able to accommodate the following criteria:

1. All software tools must be widely available as a complete software package with a user interface.
2. Include or have the capability to use accurate weather data, specifically incident solar radiation values, both direct and diffuse.
3. Account for overcast skies with a clearness index or similar technique.
4. Able to use complex 3-D building data.
5. Account for shadows cast by adjacent object and buildings within the model.
6. Contain appropriate solar analysis tools that can be used to accomplish the above research objectives.
7. Allows for visualization of models and analysis results.
8. Provide useful data on the solar availability of building surfaces.
9. Able to calculate how many solar panels could be installed on a buildings.

10. Estimate yearly electricity output, based on weather data, and array size and taking into account windows, and space between panel.

3.2. Method

Considering the above criteria, the research question and objectives, an approach using 3-D computer modeling has been chosen. Since the aim of this research is not to develop a new software tool, but rather to combine a set of software tools in a procedural workflow that will produce the desired results. The 3-D modeling software tools available to achieve the desired tasks outweigh those available in the realm of GIS. It should also be noted that this research is not intended to require programming any customized analysis tools. The main reason for this is that would violate one of the criteria set above, since a custom tool would only be for this specific research project and not available to the general public.

There are four main software packages that are capable of 3-D modeling and solar irradiation analysis. The first RADIANCE, mentioned above, is a rather powerful program; however, it is a command-line driven program that requires a high level of programming skill and is mainly intended as a research tool to improve algorithms. The second and third options are similar to ESP-r and EnergyPlus which are able to use and create 3-D building models, and both use similar techniques to calculate shadows. ESP-r does have a user interface but still requires some programming skills to run analysis. EnergyPlus however, runs a script that can be imported into a third-party plugin, such as Google Sketch Up for visualization. The main issue with these programs is the lack of a coherent user interface and established solar analysis tools. It is also unclear whether they can handle large 3-D models consisting of many buildings and terrain.

The final software option, and the one that was used, is an Autodesk program called Ecotect Analysis 2010. This software package has the most developed user interface and offers the best array of analysis tools. Since it is an Autodesk program it is based on CAD and can accommodate complex 3-D building models with ease. Also, it employs one of the better methods for shadow analysis that of shading masks. As the most developed software package it uses OpenGL to produce the required visualizations, as well as many export options to VRML, ESP-r, RADIANCE, and EnergyPlus. Although, analysis of insolation and shadowing are the main focus, visualizations are a key output of this study, since they are an effective communication tool to illustrate and justify chosen surfaces for solar applications.

3.3. Procedural Workflow

The workflow shown in Figure 3 is designed to be a guide for anyone trying to map the solar potential of building surfaces. It is not unique to any one specific software tool or even method. One could even use a GIS based software instead of a CAD based tool. This workflow simply outlines three basic steps: 1) the creation of something to analyze in this case a 3-D building model of a chosen study area; 2) conducing some form of analyses specific to the end goal, which for this research is a solar access analysis, and finally 3) the conversion of the results from the second section into a useful metric, in this case an estimation of yearly solar PV output.

The first section dealing with the creation of a building model beings with the selection of a study area followed by attaining all relevant data needed. Once the data has been attained the process of converting it into the proper format, importing it into a chosen software, and preparing it for analysis can begin. The final steps in this section is crucial to avoid any unnecessary calculations of surfaces that are already occupied. For the purposes of this research Google Earth was used because it offed the most updated aerial images.

With the 3-D model complete and all building catalogued the process of conducing analysis can begin. As mentioned above Solar Access Analysis is run using Ecotect Analysis 2010. The first step in this process is to load the appropriate weather data for your region. In some cases is may be necessary to procure and import an external weather data file depending on the region. With the weather data loaded an accurate shading mask can be calculated and an SAA run on each surface yielding either total sunlight hours or kWh/m^2 per year.

Using the final results from the SAA it is finally possible to determine how many solar panels can be installed and estimate how much electricity could be expected in a year. To

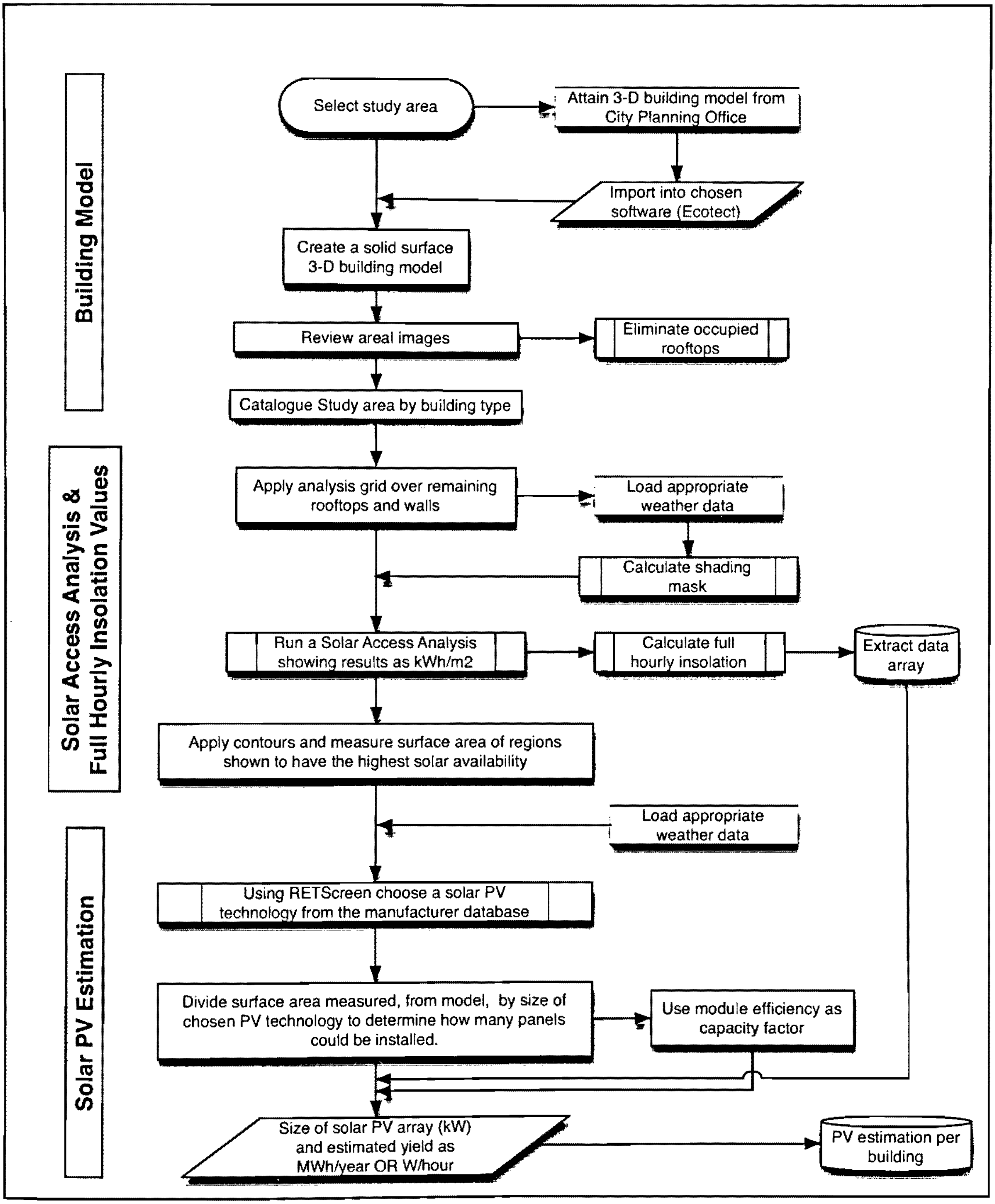


Figure 3: Procedural workflow outlining, in detail, the stepts taken to attian final restuls

accomplish this it is necessary to use a different software tool, which similar to Ecotect required the loading of a weather data file. With the data file loaded it is now possible to preform the necessary calculations to produce a final estimation of expected electricity yield. Included in this section of the workflow is the step to account for a more accurate capacity factor.

The benefit of this workflow is that is provides the basic steps to estimate the solar energy potential on building surfaces but is not specific to any one software program. Also, the model can be added to or refined depending on the desired results.

3.4. Study Area

The study area chosen represents a typical high density urban area common in large city centers around the world. As a common urban area the study area contains diverse building types in terms of age, height, overall size and function. The variety of building types makes this a prime, yet difficult study area to estimate solar energy potentials. This area it also offers many viable surfaces to analyze for solar PV applications. As noted above densely populated urban centers generally have electricity supply and demand deficits; therefore, it is advantageous to analyze such an area with the goal of categorizing limiting factors.

The area shown in red in Figure 3 contains other non-Ryerson buildings, that for simplicity sake will not be included in the overall study. Table 1 below presents a list of all Ryerson owned buildings. The table lists each building by building code or abbreviation with the the full name and street address. Each building is listed as either a low, medium or high-rise structure to illustrate the variations in the study area. Also, included is whether or not the building is included in the final 3-D building model, and for those not in the model a reason is provided. The most common reason is related to missing data from the City of Toronto file. A

Table 1: Campus Buildings Included in Study Area

Building Code	Name	Street Address	Type (low/Mid/ high-rise)	Included in 3-D Building Model	Reason for Exclusion
AMC	Toronto Life Square	10 Dundas Street E	High-rise	Yes	
ARC	Architecture Building	325 Church St	Low-rise	Yes	
BKS	Bookstore	17 Gould St.	High-rise	Yes	
CED	Heaslip House, The G. Raymond Chang School for Continuing Education	297 Victoria St.	Low-rise	Yes	
COP	Co-operative Education and Internship	101 Gerrard St. E.	Low-rise	No	Missing data
CPF	Campus Planning and Facilities	111 Bond St.	Low-rise	Yes	
ENG	George Vari Engineering and Computing Centre	245 Church St.	Low-rise	Yes	
EPH	Eric Palin Hall	87 Gerrard St.	Mid-rise	No	Missing data
GER	Research/Graduate Studies	111 Gerrard St.	Mid-rise	No	Missing data
HEI	Heidelberg Centre - School of Graphic Communications Management	125 Bond St.	Low-rise	Yes	
ILC	International Living/Learning Centre	133 Mutual St.	High-rise	No	Missing data
IMA	School of Image Arts	122 Bond St.	Mid-rise	Yes	
JOR	Jorgenson Hall	380 Victoria St.	High-rise	Yes	
KHE	Kerr Hall East	340 Church St.	Low-rise	Yes	
KHN	Kerr Hall North	31/43 Gerrard St. E.	Low-rise	Yes	
KHS	Kerr Hall South	40/50 Gould St.	Low-rise	Yes	
KHW	Kerr Hall West	379 Victoria St.	Low-rise	Yes	
LIB	Library Building	350 Victoria St.	High-rise	Yes	
MON	Civil Engineering Building	341 Church St.	Mid-rise	No	Missing data
OAK	Oakham House	63 Gould St.	Low-rise	Yes	
OKF	O'Keef House	137 Bond St.	Low-rise	No	Missing data
PIT	Pitman Hall	160 Mutual St.	High-rise	Yes	
PKG	Parking Garage	300 Victoria St.	Mid-rise	Yes	
POD	Podium	350 Victoria St.	Low-rise	Yes	
PRO	Project Office	112 Bond St.	Low-rise	Yes	
RAC	Recreation and Athletics Centre	40/50 Gould St.	Low-rise	No	Underground building/ Missing Data
RCC	Rogers Communications Centre	80 Gould St.	Low-rise	Yes	
SBB	South Bond Building	105 Bond St.	Low-rise	Yes	
SCC	Student Campus Centre	55 Gould St.	Low-rise	Yes	
SID	School of Interior Design	302 Church St.	Low-rise	Yes	
THR	Theatre School	44/46 Gerrard St. E	Low-rise	Yes	
TRS	Ted Rogers School of Management	575 Bay St.	Mid-rise	No	Outside Study Area
VIC	Victoria Building	285 Victoria St.	Mid-rise	Yes	
YDI	Young-Dundas	1 Dundas St. W.	High-rise	No	Outside Study Area
YNG	415 Young St.	415 Young St.	High-rise	No	Outside Study Area

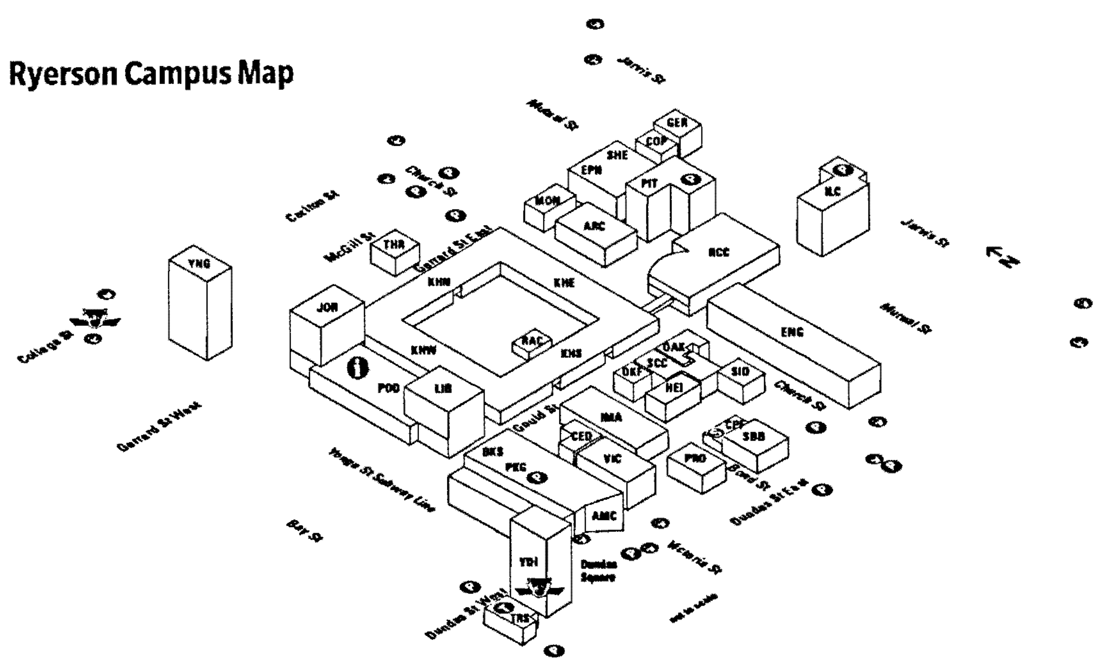


Figure 4: Campus Map by Building Code.
Note: this map is not to scale or accurate to any building design

more detailed explanation will be given in the results section.

3.5. Building Model

Creating a scaled and accurate 3-D building model for computer analysis can be rather challenging depending on the level of skill of the user or the type of raw data attained. Issues with raw data, however, can be very time consuming and can require the acquisition of third party software to convert between formats.

For this research a study area of one city block encompassing Ryerson University campus was chosen (See Figure 5). The City of Toronto provides access to detailed and geographically accurate 3-D building data. Upon signing a data acquisition and release form, the data for the study area was attained, free of charge, from the City of Toronto Planning Office (see Appendix A). This data is offered through a program called the Enterprise Stereographic Model, which uses stereo pair satellite images and a program called Microstation to produce the raw elevation data for buildings, using an imbedded MTM NAD 27 coordinate system. This data is offered in DGN, DWF and DXF formats.

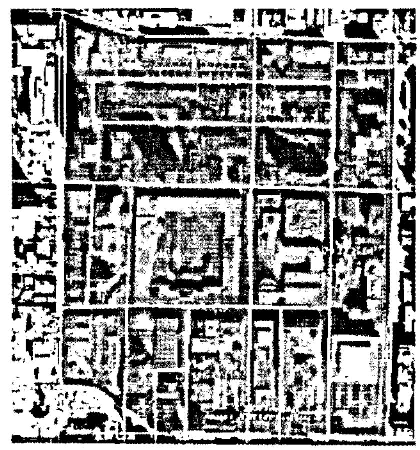


Figure 5: Study area

When the data was originally requested it was rather early in the overall research process and it was unclear what software packages was going to be used or what format would be best; therefore, the data was attained as a DGN file. Ecotect is not able to use or convert .dgn files. Therefore, it was necessary to use AutoCAD to open the file and save it as .dwg file. Unfortunately, there was a much larger problem with the data that was not foreseen. The DGN file consisted of building footprints with rooftops as elevated cross-sections, meaning that each building was not a solid structure of walls and rooftops. This was a significant issue and required the manual manipulation of the data to create walls. This was accomplished in AutoCAD using two functions called lofting and extruding. Although this was extremely time consuming and difficult at times, it was effective and the final result was a completed solid structure 3-D model of the study area.

For best results Ecotect required the data file to be imported in .3ds format. This problem was overcome by importing the 3-D data into Autodesk 3DS MAX Design and saving the file as a .3ds file. With a completed 3-D building model in 3DS format it is now possible to import the data into Ecotect Analysis 2010. This was accomplished through a simple import tool that allowed the user to chose the file and specific features to be imported. Also, in this dialogue the scale of the model was set. In this case it was set to 1000, converting from meters to millimeters. This allowed the model to fit within an Ecotect analysis grid, yet with the scale set, all measurements would be shown as meters or meters square for surface area.

When it was initially imported the model was not aligned to a floor grid, meaning that it was not possible to perform an analysis calculation. This required simply moving the point of origin for the model such that it was aligned to a floor grid. The geographical information or orientation is still present, set in a parameter for latitude and longitude as well as North Offset. The North offset for the study area was set at -15°. This reorients the angle of the sun-path diagram changing the overall position of the sun. This parameter is similar to a calibration, and if not set would result inaccurate analysis of building surfaces.

The original building model contained all buildings within the study area; however, for the purpose of this research only those buildings that are part of Ryerson University Campus were of interest eliminating most other buildings. However, some buildings, not part of the campus, were kept since they were perceived to have an effect on solar access due to overshadowing (see Figure 6).

The next steps involve making surfaces of each building functional within Ecotect. In other words, setting the proper parameters telling Ecotect that a vertical surface is an external wall and a horizontal surface is a rooftop. The first step in this process is to ensure that all walls and roofs are oriented outwards. This is done by checking surface normal which shows an arrow

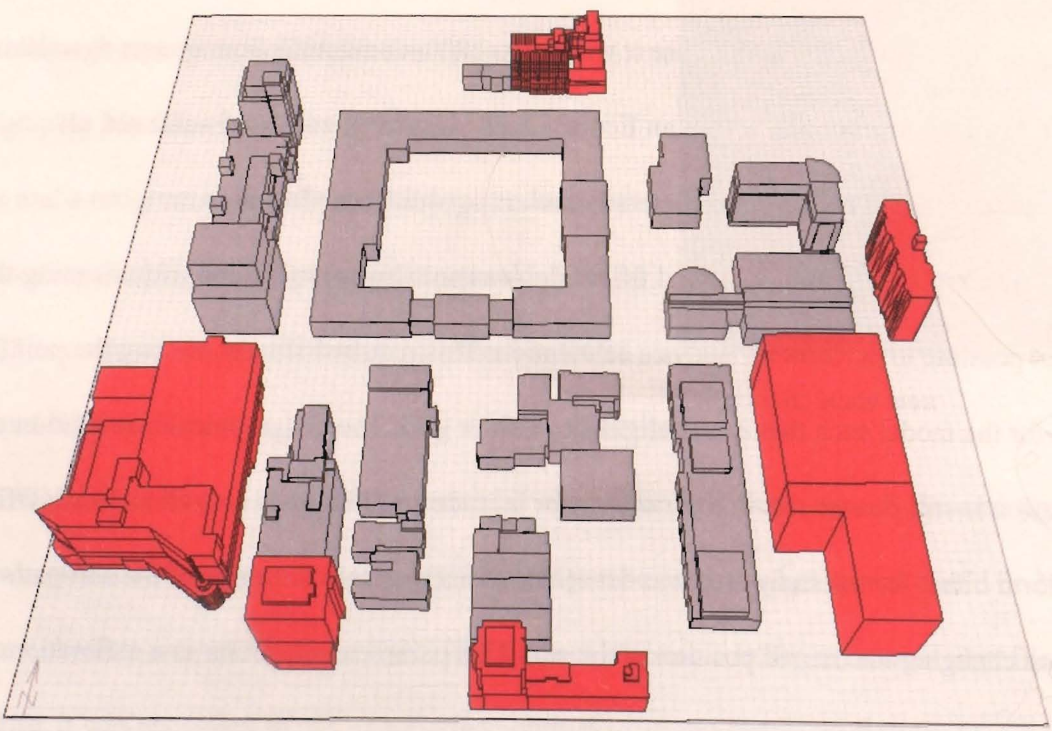


Figure 6: Completed building model in Ecotect with buildings to be analyzed show in grey and other non-Ryerson buildings needed for shading calculations shown in red.

pointing inwards indicating an interior surface or outwards indicating an exterior surface. A surface cannot be both at the same time it is either one or the other.

The next step involved calculating zone volume of each object so Ecotect is able to determine the size of each building. This is not crucial for this type of analysis but is necessary for analysis involving interior acoustics and daylighting. The most important step in this process is calculating inter-zonal adjacency, which tells Ecotect how close each building is to each other. Without this calculation it is not possible to run an accurate shading mask calculation or any other analysis.

3.6. Solar Access Analysis

A Solar Access Analysis (SAA) is one of many solar related analysis that Ecotect is able to conduct. Even within the SAA dialogue there are numerous options that need to be taken into account to ensure that an accurate and relevant outcome from the analysis. The first step in this process is to load the appropriate weather file, which comes with the program, in this case Toronto, Ontario Canada. This weather file consists of solar irradiation data, mainly direct and diffuse components. Ecotect does allow for user to import a weather file from an independent weather station or database if desired.

The next step, which is the most important, is to calculate a shading mask for south facing walls and all rooftops individually. It was determined based on observation and through the literature review that only south facing walls are worth while. In conducting preliminary SAA's on east and west facing facades the results returned showed rather low irradiation and extensive overshadowing. This is due to one inherent limiting factor embodied in the shading mask that of the sky factor. The sky factor is a measure the proportion of the sky a surface is

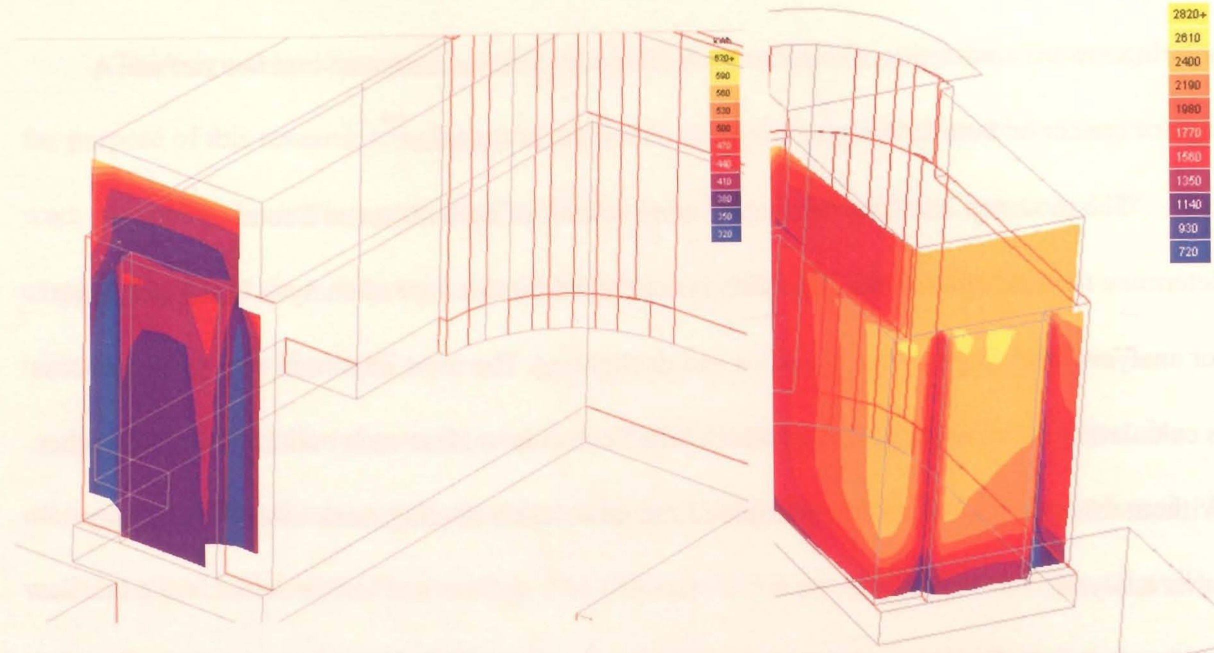


Figure 7: Pitman Hall west facade (left image) showing the lower irradation values. The right image shows Pitman Hall south facing facades which has much higher values.

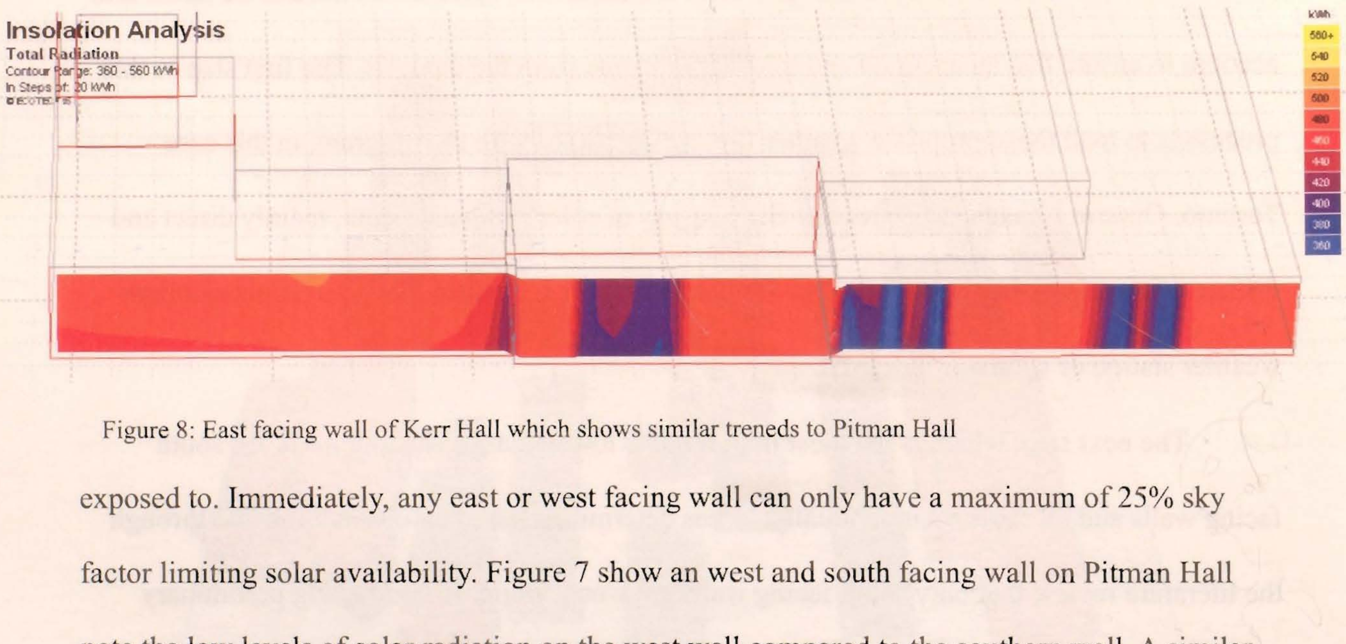


Figure 8: East facing wall of Kerr Hall which shows similar treneds to Pitman Hall

exposed to. Immediately, any east or west facing wall can only have a maximum of 25% sky factor limiting solar availability. Figure 7 show an west and south facing wall on Pitman Hall note the low levels of solar radiation on the west wall compared to the southern wall. A similar trend is seen on the east facade of Kerr Hall shown in Figure8.

A shading mask is a rather useful method for calculating how much shading a surface receives due to adjacent objects. Ecotect uses a point based approach across a uniform and overcast sky. The effects of shading on a surface can be extreme in urban regions where there are many lower rise buildings surrounding by much taller structures. Furthermore, the shadowing is not consistent throughout the day or year. The extent of a shadow is directly correlated to the angle, or azimuth of the sun in the sky and changes in the summer solstice and winter equinox. The shading mask is able to incorporate all this information into one calculation for the whole year by averaging daily values. It deals with changes in shadows range by applying a shaded gradient to each object in the mask over a grid set by the user.

Another major factor incorporated into the shading mask is a sky factor. A sky factor is a measurement of how much sky a surface is exposed to or is obstructed. In Ecotect this is calculated by applying 200 points across both a uniform and overcast sky. Each point that

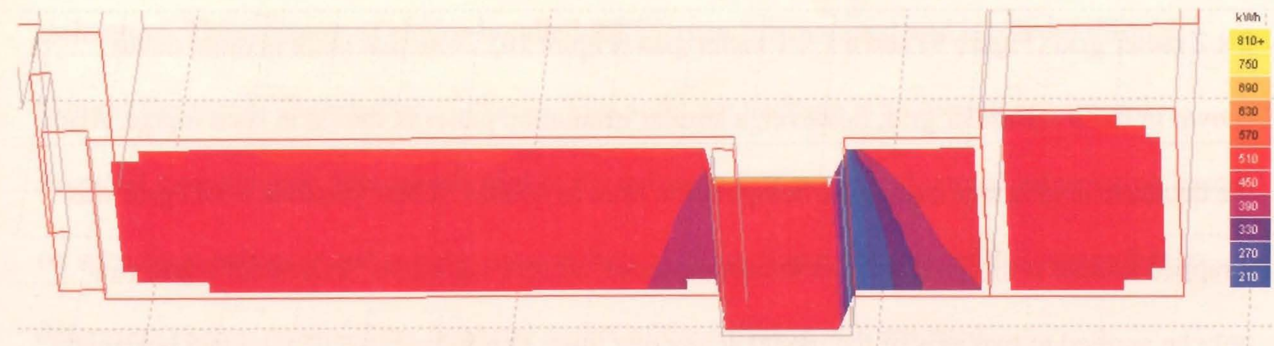


Figure 9: Imaging Arts building with a 2 x 2 meter grid

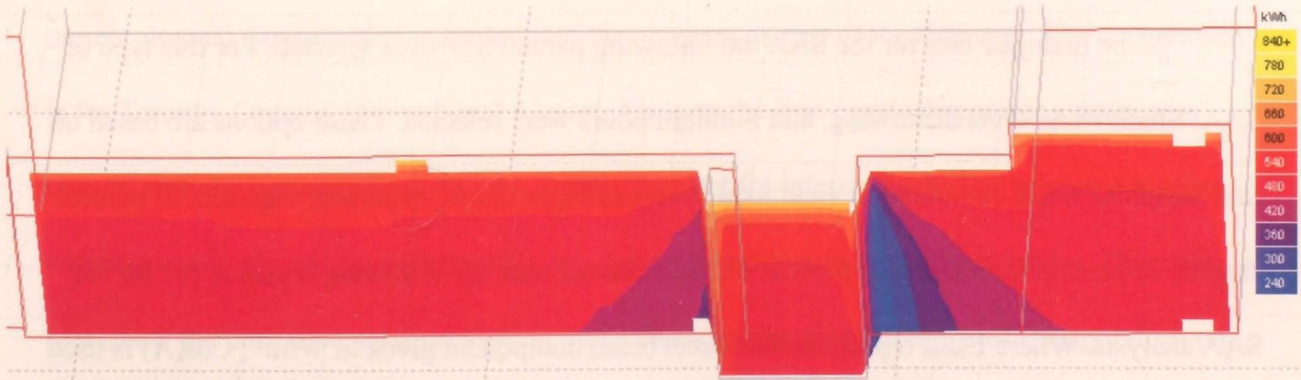


Figure 10: Imaging Arts building with 1 x 1 meter grid

intersects an object is accounted for reducing the sky factor by a certain percentage. The more points that intersect objects the smaller the sky factor is. Horizontal surfaces (rooftops) can have a maximum exposure of 360° and for vertical surfaces (walls) a maximum of 180° is possible. This is an inherent limitation based on a surfaces physical properties. Obstacles are then added into the equation further limiting the sky factor. In other words a sky factor is the percentage of the sky a surface has access to.

With the appropriate weather file loaded and a shading mask calculation done an SAA can be run (see Appendix B). The first step is to apply an analysis grid to the surface being analyzed. In this case for all surfaces a 2 x 2 meter grid was used. This size was chosen because it allowed for the desired level of accuracy and detail without compromising processing time. For comparison purposes the east facing wall of the Imaging Arts building was analyzed using a 2 x 2 meter grid (Figure 9) and a 1 x 1 meter grid (Figure 10). Note that there is more detail shown in the 1 x 1 meter grid; however, a similar irradiation patter is shown in each image. Also, the decrease in grid size causes the computation time to double. Where possible a 3-D grid was wrapped around rooftops and walls to encompass all surface variations. In Ecotect a grid can only be applied to two axis of the model at any one time. This means that vertical and horizontal surfaces cannot be analyzed at the same time; therefore, all surfaces were analyzed separately.

In the dialogue box for the SAA the following parameters were selected. For this type of SAA: Shadowing, Overshadowing, and Sunlight hours were selected. These options are based on four variables when combined to yield total yearly sunlight hours: 1) percent exposed, 2) percent shaded, 3) percent direct, and 4) percent diffuse. Ecotect uses the following equation (1) for the SAA analysis. Where E_{beam} represents the direct beam component given in W/m^2, Cos(A) is used for the angle of solar incident and $E_{diffuse}$ for the energy available from the entire sky dome, minus direct radiation, given in W/m^2. F_{shad} as the fraction of surface currently in shadow from other surrounding geometry and F_{sky} for the fraction of diffuse sky actually visible from surface. For time period the whole year was chosen based on cumulative insolation values.

$$E_{incident} = [(E_{beam} \times \cos(A) \times F_{shad}) + (E_{diffuse} \times F_{sky})] \times ExposedArea \quad (1)$$

3.7. Solar PV Estimation

As useful as Ecotect is in this overall process, it is not able to estimate how much electricity can be generated in a year, given a specific solar PV technology. To accomplish this task another software package was required, due mainly to the surprising complexity of such estimation. The software of choice is called RETScreen International and is offered through Natural Resources Canada free of charge. This software package is an overall energy and financial analysis tool. The overall goal of the software is to provide financial information based on specific scenarios to aid in a decision making process. Since, the goal of this research is to determine energy potential the financial aspect of the software will not used.

Similar to Ecotect, RETScreen has a weather data file supplied from NASA's meteorological database that is loaded into the program as part of the first step. The data chosen is for Toronto, Ontario, International Airport. Also, on the first page solar power system was chosen with the option to feed into the central grid and for internal load. The next step involves entering yearly electricity consumption data for each building in the Ecotect model. This data represents the base case scenario used to make financial decisions in terms of energy return on investment (EROI). Since RETScreen was not be used for financial investment, this electricity consumption data was used as a base of comparison for the results of the RETScreen electricity estimations.

A main benefit of using RETScreen is that it offers an extensive database of solar panel technologies available for use in Canada, which includes, measurements and efficiency ratings. The measurements for each panel are given as the surface area a specific panel will occupy. This number is then divided by the best available surface area including space needed for installation to determine how many panels could be installed on a surface. The number is entered into the dialogue box along with the chosen PV technology. RETScreen converts those numbers into a power capacity given in kW for that array. Considering the weather data, angle of installation (15°), array capacity in kW and the panel efficiency RETScreen provides an estimation of the yearly electricity output in MWh/year. Beyond the above steps a more detailed calculation can be done based on the inverter use which alters the capacity factor. The capacity factor represents the overall system efficiency as a percentage which RETScreen calculated to be 14.1%. Weather data can be seen in Appendix C.

4. Results

This chapter will begin with a discussion of the general findings from the Solar Access Analysis and some limitation experienced within Ecotect. The results of each building will be discussed individually with all accompanying images in Appendix D. The chapter concludes with the calculations and results from RETScreen.

4.1. Ecotect SAA

The initial SAA's of rooftops was conducted before the addition of non-Ryerson owned buildings. The results of this were very favorable showing almost entire roof areas as suitable for solar applications. Figure 11 shows the RCC SAA prior to the addition of the high-rise building to its immediate right. Notice that almost the entire surface is shaded in yellow. However, once

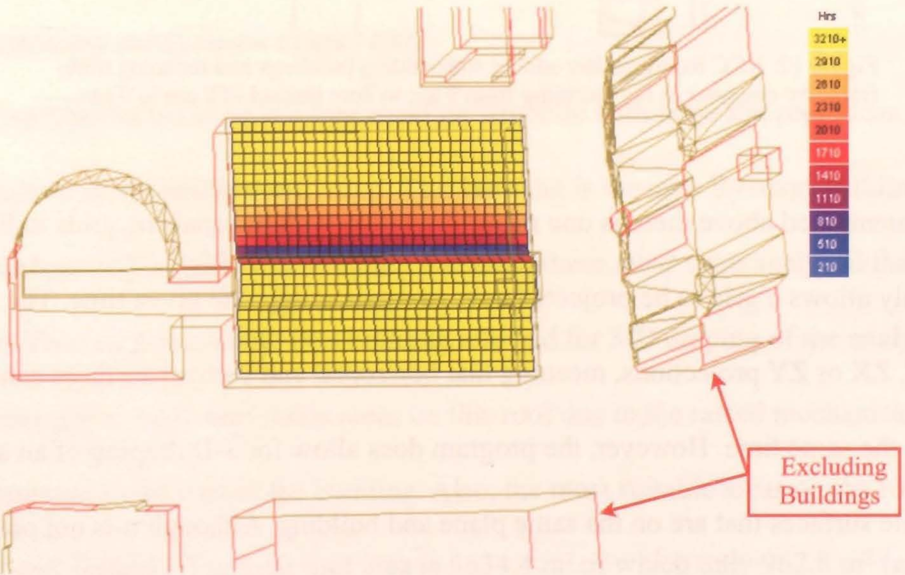


Figure 11: Rogers Communication Centre SAA first attempt. This image shows the solar potential of a portion of the RCC roof without the two larger building to the east and south of the RCC.

the high-rise building is added only a small fraction is shaded in yellow. Initially these changes were an issue, but in running shading simulations it was determined that the RCC is heavily shaded until approximately 9:00 am. Therefore, the SAA time frame was shortened by one hour from 8:00 am to 9:00 am, which produced a more accurate representation of irradiation on that surface, (see Figure 12).

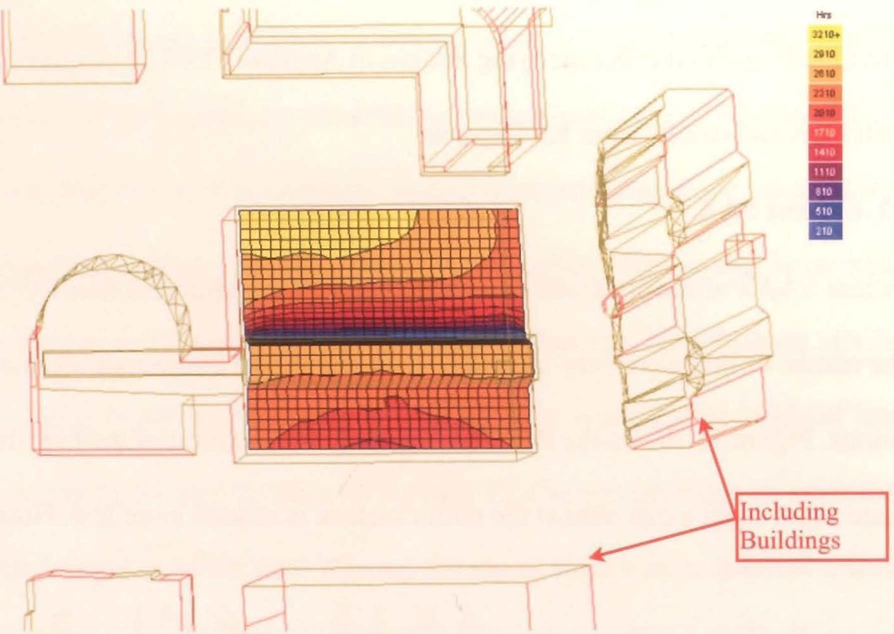


Figure 12: RCC Rooftop after adding surrounding buildings and reducing time-frame by one hour in the morining from 9 am to 9pm instead of 8 am to 9 pm.

As mentioned above there is one major limitation with the analysis grids in Ecotect. The program only allows a grid to be projected over two axis at any one given time. The only options are and XY, ZX or ZY projections, meaning that horizontal and vertical surfaces cannot be analyzed at the same time. However, the program does allow for 3-D draping of an analysis grid over multiple surfaces that are on the same plane and building. Although it is not possible to drape an analysis grid over an entire building, it is possible to perform an SAA over a complex rooftop or group of south facing walls on one building. The south facing walls of Pitman Hall and Engineering building rooftops are good examples of this. Unfortunately, Ecotect can only drape an analysis grid over objects that have four unobstructed or unattached sides. In other words an object must be placed freely on top of another object for 3-D draping to work. Therefore, some rooftops were analyzed using two separate grids in cases where surfaces were large enough to warrant calculations, such as Podium rooftop.

To attain a measurement from the SAA results a polygon is drawn within the yellow regions of the analysis grid following the outline as best as possible. The individual results of each buildings surface can be seen in Appendix E. There is an individual summary report for each building which includes:

- A zoomed 3-D image of each specific building
- Aerial photo of rooftops
- A calculated orthographic shading mask
- SAA results for rooftops and south facing walls

George Vari Engineering and Computer Centre - ENG

The Engineering building is a free standing structure with large flat roof areas. There are three raised square structures on the rooftop. This building is the only Ryerson building with a large green roof, as well as one large skylight. Although these areas were analyzed they were excluded from final measurements. This building allowed for 3-D draping of the analysis grid. The SAA results show many unsuitable areas on this roof due to the raised mechanical housings and a large structure to the east of the building. Also, the most suitable areas on the rooftop were the greenroof and skylight. The total roof area is 5634.4 m^2 of which only 962.8 m^2 (about 17%) is suitable for solar installations. This building only has one south facing wall measured 393.1 m^2, only 17 % was suitable.

Architecture Building - ARC

The first thing to note about this building is the inconsistency with the 3-D building data and resulting model compared to the aerial photo. There are two large raised mechanical enclosures not included in the 3-D model. The effects of these would be similar to that of the Engineering building. However, based on the SAA only one of the structures is a concern. This would mean that a portion of the roof directly behind and to each side of the structure would not be suitable for solar applications. Since these features were not included in the building model, rooftop measurements are based on a completely flat surface. Besides the raised mechanical enclosures there were no other distinctive limiting features on this rooftop. Total roof area is 1830.4 m^2 and based on SAA results 521.6 m^2 is suitable for solar applications. This building has one south facing wall and based on the SAA there was no suitable area for solar applications.

The G. Raymond Chang School of Continuing Education -CED

This building posed significant challenges. It is a rather new building with complex architecture and odd angular walls that limited rooftop area. In addition, due to the complex structure creating a 3-D building model proved difficult. Therefore, the final structure was missing some detail but still retained enough of the original data to be valid. This building is attached to a much larger structure at its south facing wall; therefore no wall surfaces were analyzed. There is one relatively small roof area that could be analyzed however it is more than 50% occupied by an HVAC system and therefore is not suitable for solar applications.

School of Imaging Arts - IMA

The Imaging Arts building is a large square building with very little occupied roof space. It is the best rooftop in terms of open space on campus. There is a south facing wall; however, it does not receive enough sunlight for solar applications. The SAA revealed that most of the rooftop is not suitable for solar applications, due to a taller building to the southwest. Of the 2455 m^2 of roof area only 9% (approximately 228.2 m^2) could be used for solar applications. This building does have long west and east facing walls, however based on the SAA it is determined that they are not suitable for solar applications.

Kerr Hall - KRH

Kerr Hall is the largest building on campus in terms of rooftop surface area with the lowest elevation. There are portions of the rooftop that are occupied with building mechanics and HVAC. However, the majority is unused. For the SAA Kerr Hall was split into three rooftop sections, based on the building model segments. The northern most part of the roof was mostly unobstructed with only small portions on the western side unsuitable due to overshadowing from Jorgensen Hall. The southeastern portion of the rooftop receives almost no overshadowing, whereas the southwestern rooftop is the opposite being almost completely overshadowed. Considering the SAA approximately 5374.6 m^2 or 39% is suitable for solar applications. This building is unique in that there are two south facing walls, one outer wall and one inner wall facing the quad. Both are suitable for solar applications offering a total of 3553.6 m^2 of surface area with 16% or 560 m^2 of suitable surface area for solar applications.

Library Building - LIB

The Library building is part of an attached complex consisting of Podium and Jorgensen Hall. The first thing to note regarding this building is that the rooftop is completely occupied with HVAC systems. This is unfortunate because it is the tallest building and is therefore completely unobstructed. The south facing wall of the building does provide some suitable surfaces. The upper portion of the wall is fairly unobstructed; however, of the 1891 m^2 only 8% is suitable for solar applications

Pitman Hall - PIT

Pitman Hall is a tall L shaped building with more wall surface area then rooftop and due to the height of the building it is completely unobstructed. Unfortunately, the largest south facing wall receives significant overshadowing because of the shape of the building. Of the possible 1847 m^2 of south facing wall only 16% or 294.35 m^2 is usable, whereas 50% of the roof space is suitable for solar applications.

Podium - POD

Podium is the middle building flanked by the Library and Jorgensen Hall buildings. It is significantly lower than both the library and Jorgensen Hall, causing it to be heavily overshadowed. This building is also an example of a surface that has a raised portion that could not be draped by a 3-D analysis gird, because it is not a complete structure only having three exposed sides. Therefore, it was necessary to run two separate SAA's. Even with the extensive overshadowing of the 2959 m^2 roof area approximately 15% is viable for solar applications.

Projects Office - PRD

The project office is a group of two separate buildings with rooftops that are mostly unoccupied. The main issue with this structure is that it is next to a much larger and taller building to its immediate west, greatly increasing overshadowing. Despite this over 44% of the rooftop is useable offering 64 MWh/year. This is possible because there are no other taller buildings surrounding it.

Rogers Communication Building - RCC

The RCC is large low rise structures with much of its rooftop open. However, it has some rather large adjacent structures to deal with. On the east side of the building there is a tall structure which overshadows almost the entire building until around 9 am. To the south of the building there is large taller structure which causes overshadowing from about 10 am to 12 noon. Despite this about 40% of the rooftop is suitable for solar installations. However, the south facing walls are the complete opposite. The building to the south almost completely overshadows a large portion of the wall making it unsuitable for solar applications.

South Bond Building - SBB

The SBB is a collection of five individual buildings, three are similar in height and two towards the north end are lower. This group of buildings is adjacent to a tall office building to the immediate north which creates substantial overshadowing. Even with this there are some portion that are suitable for solar application; unfortunately, that exact section is where the HVAC system is located. Therefore, none of the roof area is suitable for solar applications. Also, due to the proximity of the office tower there are no south facing walls.

Student Center, School of Interior Design, Oakham House and Heidelberg Centre

This is another group of four adjoined buildings. Once again the rooftops are typical with certain sections occupied by HVAC systems. Based on the SAA approximately 50% of the combined surface area is suitable for solar access. This is because there are no taller adjacent buildings. However, there is only one viable south facing wall which offers 25% of its total surface area for solar applications. There is one issue that of Oakham house, which has a pitched roof that was not included in the model because it was not in the original building data.

Victoria College - VIC

Victoria College is sandwiched between CED and a slightly taller office buildings, meaning there is no south facing wall. In addition, to the west of the building there is a large parking garage and movie theater complex. Despite this the SAA showed that about 17% of the rooftop surface is viable for solar applications

Theater School - THR

The theater building is one of the smaller campus buildings, however it does offer some benefits. Its rooftop is completely unoccupied and it does have a south facing wall. According to the SAA 50% of the rooftop surface area is suitable for solar panels and another 13% of the south facing wall. This building is attached to a much taller residence, however similar to the RCC the overshadowing effect is limited to early morning hours, limiting its overall impact.

Table 2: SAA and RETScreen results for building rooftops

Building	Total Roof Area (m^2)	SAA Results (m^2)	Percentage of Total	Number of Solar Panels (Canadian Solar mono-Si CS5P 240W)	Array Power Capacity (kW)	Estimated Electricity Yield (MWh/y)
ARC	1830.43	521.65	28%	261	62.64	78
CED	411.50	0.00	0%	-	-	-
ENG	5634.44	962.76	17%	481	115.44	143
IMA	2454.99	228.21	9%	114	27.36	34
Kerr Hall N	6540.66	3,270.33	50%	1,635	392.40	487
Kerr Hall E	3215.41	1,607.70	50%	804	192.96	239
Kerr Hall W	2902.27	514.10	18%	257	61.68	76
LIB	1456.57	276.60	19%	138	33.12	41
POD	2959.15	431.49	15%	216	51.48	64
PRO	567.74	252.40	44%	126	34.80	43
RCC	4089.63	1633.29	40%	817	196.08	243
SBB	2163.65	0.00	0%	-	-	-
VIC	1487.83	245.80	17%	123	29.52	37
PIT	1183.97	589.03	50%	295	70.80	88
JOR	785.82	246.12	31%	123	29.52	37
HEI	685.89	342.95	50%	171	30.96	38
SCC	1056.24	528.12	50%	264	63.36	79
OAK	468.92	234.46	50%	117	27.84	35
THR	367.08	184.22	50%	92	22.08	27
SID	1110.68	555.34	50%	278	66.72	83
Total	41,372.87	12,624.58	31%	6,312	1,508.76	1,872

4.2. RETScreen Solar PV Estimation

Compared to the SAA RETScreen is rather straight forward. One specific solar panel technology is chosen. A Canadian Solar 240 W panel chosen for its power capacity, efficiency of 14% and overall design. Using the size of the panel given as 1.7 m^2, which was rounded up to 2 m^2 to account for space required for installation. Table 2 shows the results of the SAA for each building rooftop, and the resulting RETScreen calculations. Based on the SAA 31% of total rooftop surfaces is viable allowing for 6,367 solar panels which translates into a total array power capacity of 1.6 MW producing approximately 2 TWh/y of electricity.

Table 3 shows the SAA results for south facing walls and the accompanying RETScreen calculations. The first thing to note is that only buildings with viable south facing walls have RETScreen calculations in the above table with only 7 of 18 Ryerson owned buildings being analyzed. Based on the SAA only 15% of total wall surface area is suitable for solar applications

Table 3: SAA & RETScreen results for south facing walls

Building	Total south facing walls (m^2)	SAA Results (m^2)	Percentage of Total	Number of Solar Panels (Canadian Solar mono-Si-CS6P 240 W)	Array Power capacity (kW)	Estimated Solar PV Electricity Yield (MWh/year)
ARC	0.00	0	-	-	-	-
CED	0.00	0	-	-	-	-
ENG	393.12	65	17%	33	7.92	10
IMA	0.00	0	-	-	-	-
Kerr Wall S	3553.63	579.834	16%	290	69.6	86
LIB	1891.08	150.69	8%	75	18	22
POD	0.00	0	-	-	-	-
PRO	0.00	0	-	-	-	-
RCC	0.00	0	-	-	-	-
SBB	0.00	0	-	-	-	-
VIC	0.00	0	-	-	-	-
PIT	1846.90	294.35	16%	147	8.4	10
JOR	1024.83	165.488	16%	83	19.92	25
HEI	0.00	0	-	-	-	-
SCC	0.00	0	-	-	-	-
OAK	0.00	0	-	-	-	-
THR	360.53	47.85	13%	24	5.76	7
SID	482.11	103.672	22%	52	12.48	15
Total	9,552.208	1,406.884	15%	703	142.08	175.0

which translates into 606 panels with a total array capacity of 142 kW and an estimated electricity output of 175 MWh/year. This is substantially less than the combined rooftops.

5. Discussion

Overall, the SAA and RETScreen calculations produced the desired results. The best possible surfaces areas on Ryerson owned buildings were identified and measurements taken. The measurements were converted into an estimation of yearly electricity output. The final step in this analysis is to compare the results to see how much total electricity consumption could be offset. As shown in Table 4, the total solar energy could only cover 4.7 % of total energy demand for the university. Although 2 TWh seems substantial, compared to the 43 TWh of electricity

Table 4: Combined RETScreen results vs. Total building electricity consumption

Building	Estimated Solar PV Electricity Yield (MWh/year)	Total Building Electricity Consumption (MWh/year)	Percent offset by solar
ARC	78	969	8.0%
CED, IMA, VIC	71	3,359	2.1%
ENG	153	4,115	3.7%
Kerr Hall	898	7,239	12.4%
LIB, POD, JOR	189	19,698	1.0%
PRO	43	111	38.7%
RCC, PIT	341	5,322	6.4%
SBB	0	736	0.0%
HEI, OAK, SCC	152	1,675	9.1%
THR	41	226	18.2%
SID	98	339	28.9%
Total	**2,064.0**	**43,789**	**4.7%**

required by the university it is not very much, making these final results slightly less positive than initially hoped. The point remains that the workflow and software tools chosen provided the desired results, meaning all objectives were met.

It was expected that facades would be less suitable for solar applications, which was the conclusion; however, many rooftops were also unsuitable for solar applications. The issues with HVAC systems and green roof seem to be more severe than issues with overshadowing. The amount of surfaces occupied by HVAC systems was not foreseen and speaks to the difficulties of placing solar panels on existing rooftops. Of the twenty campus buildings, four were eliminated because their rooftops were 50% or greater occupied by HVAC systems.

This issue is unfortunate but understandable due to age of most campus buildings. Many are half a century old or more, others were built during the 60's and 70's when consideration for solar panels was not an issue. The newer buildings seemed to have more compact HVAC systems, allowing for more free rooftop space; however, in the case of the Engineering building other environmental considerations, specifically a green roof and natural lighting via large skylights took priority. It is difficult to conjecture why green roof and skylights took priority over renewable energy, however, it may be fair to say that cost might have been an issue. Although the engineering building is relatively new when it was constructed there was no FIT program providing large financial incentives as there are today.

Despite the issue with HVAC systems and green roof, the majority of rooftops and facades received varying amounts of overshadowing often with the most heavily shaded regions ranging approximately 1000 hours less than the least shaded. The variations are caused directly by taller adjacent buildings as initially expected. Since the main goal of this overall process was to account for overshadowing the extent of which is somewhat surprising. Referring to the final building model in Ecotect (Figure 4), the additional building shown in red, had a substantial affect on Ryerson buildings mainly due to their hight and overall size.

Regardless of the outcome, the SAA proved to be a crucial tool to determine where to locate solar arrays on buildings. In urban areas it is not sufficient to simply assume that an unoccupied roof space or south facing facade is suitable for solar applications. Although a uniform insolation value may be used for electricity generation calculations, knowing the best possible places to locate arrays is important. Ideally, one program would be able to combine the functions of an SAA and electricity generation estimation. The benefit of this approach would allow for a range of estimation calculations based on the surface area of each contour and accompanying SAA value, either in total sunlight hours or kWh/m^2 / year. The benefit to this method is not only that one program does all the work, but a more accurate non-uniform insolation measurement would be used.

There are two much larger issues that the overall results embody: 1) that of limited solar PV technology; and 2) energy efficiency and conservation (EEC). The latter of the two issues, energy efficiency and conservation, is more easily rectified than any limitations with solar PV technology.

5.1. Solar PV Technology

Although this research is focused on solar modeling and PV system estimations there has been little discussion of solar PV technology itself. There are two reasons for this: 1) this research focused on estimating solar potentials on buildings, and 2) the technology behind solar PV technology is complex, easily requiring a separate thesis to fully explain. Therefore, the next section will briefly discuss the general state of solar PV technology and possible future developments, focusing on its inherent limitations. The goal here is not to be critical of solar PV's but rather to explain why the overall results are not higher.

Solar PV technology is currently dominated by Crystalline Silicon Solar Cell technology developed in the 1980s. Crystalline Silicon solar cells range in efficiencies from 13% to 19% and can be as high as 24% (Asano and Saga, 2009). The more efficient a solar cell the more electricity is converted for every watt of sunlight that is absorbed per m^2, improving output and reducing the cost. A major advancement in this specific PV technology was developed at the University of New South Wales, allowing for the contacts in wafers to be buried, increasing surface area. Issues with conventional Crystalline Silicon technology are related to the required thickness of a silicon wafer, needed to allow light absorption over a wide range of wavelengths (Green, 2004).

To combat this new approaches were developed such as Back Contact structure, increasing surface area and HIT (heterojunction with intrinsic thin layer) developed by Sanyo have been implemented. HIT seeks to produce a high quality surface on both the front and back of a panel, increasing surface area and conversion efficiency without increasing manufacturing cost. This is achieved through combining many layers of cells using both amorphous and crystalline cells, which absorb different wavelengths of light (Asano and Saga, 2009).

The second generation of solar technology is referred to as thin-film based on amorphous silicon, which has a higher absorption coefficient compared to crystalline silicon; however, it suffers from lower conversation efficiency. This can be overcome with HIT technology producing a tri-layer structure with efficiencies over 8%. Other benefits of thin-film technology include improved performance at higher temperatures, lower production costs due to lower material requirements and ease of application of inexpensive substrates (Green, 2004).

5.2. Energy Efficiency and Conservation

The goal of any energy efficiency and conservation (EEC) work is a net reduction of total energy demand or consumption. Reducing electricity demand not only lowers electricity bills; but also makes renewable, such as solar, more attractive since they will be able to offset a larger percentage of total energy consumption without any change in solar PV technology. Beyond the issue of renewables, it is simply a prudent course of action for society at large to pursue aggressive energy efficiency and conservation programs to ensure electricity is not being wasted or consumed unnecessarily.

In any typical building electricity consumption is accounted for by HVAC systems, technology (computer labs, servers, AV equipment), vending machines that run 24 hours and finally lighting. Technology can be considered a huge but necessary drain, which has major limitation for EEC, considering that beyond sleep timer settings for monitors and CPU's electricity consumption is static for that model and cannot be reduced without the purchase of a newer more energy efficient model. This scenario holds true for all technology; however, this issue can be remedied with regular hardware upgrades.

Energy efficiency in HVAC systems, on the other hand, cannot be easily remedied considering their size and permanent nature, meaning that replacing or upgrading HVAC units for EEC purposes can require major capital investment and retrofits. With HVAC systems electricity is required to run all the blowers and fan for ventilation, any electric radiators or boilers and the largest consumer air conditioners. Heating in general does not consume large amounts of electricity, since most buildings rely on natural gas as a heat source, using either boiler and radiators or forced air systems.

Reducing electricity consumption of HVAC systems, through retrofits, can be very difficult due to the complexity of systems design, function and the need to control heat exchange. Heat exchange refers to the movement of air in and out of a building through, windows, doors and air exchange units. The final issue with HVAC systems, which is also a costly one due to the technical changes of retrofits, is upgrading the overall functionality and design of a system. In the case of many older buildings constructed over the last 50 years, the control of any one room or area of a building is quite limited. Often these systems only have an on or off mode with limited speeds, resulting in a one size or one setting fits all approach.

There may also be issues with old mercury thermostats which may not be accurate or functional. It would be advantageous to have only digital thermostats that allow for limited control of temperature to limit extreme fluctuations. Also, many older systems cannot easily cycle up or down offering the instantaneous response most people expect. This means that a system may be working harder overall to cool or heat certain rooms than is necessary to achieve a small temperature change, ultimately wasting energy. Having a flexible HVAC system can make better use of ventilation and achieve the desired temperatures with much less effort and energy.

Finally, the last electrical drain is lighting, which is often given the most attention because it is the most noticeable form of electricity consumption. Although, lighting is important it tends to already have some efficiency measures with florescent and compact florescent bulbs. The main issue with lighting is run time, or the hours a fixture is on. Ideally, all lighting would be either on timers, or motion and light sensors. This would mean that lighting systems would naturally be in the off position and only turn on when needed. The technology exists, however similar to HVAC systems it is expensive and difficult to retrofit older buildings that are not originally designed to operate in this way.

Although this research was not aimed at EEC measures, based on the comparison of results in Table 3 it is obvious that the two are closely related. In fact, it can be argued that until

EEC measures have been exhausted it does not make sense to install renewable energy on a building simply to provide more supply or to get government grants. Renewable energy is a good supply option, but has inherent limitation, and therefore cannot be wasted because of systemic inefficiencies.

The two issues discussed above fuel the general perception that solar is not a good supply option or is simply too expensive. In reality, limited solar PV technologies and inefficient over-consumption of electricity has lead to a perfect scenario where an abundant renewable source of energy appears inferior to other sources of energy. Fortunately, there are many ways that this imbalance can be resolved. There are economic measures that can be taken to reduce the financial risk of installing solar PV or there can be systematic efficiency improvements to the grid as a whole. The first option is much simpler to implement because it involves offering incentives that cover the capital investment of a solar project. Feed-in-tariffs are a good example of a tool used in this approach.

Although feed-in-tariffs are a good method to encourage investment in renewables and there is no doubt that FIT programs increase renewable supply (IEA, 2008). The question remains what exactly is this renewable supply feeding into? Is it supplying an energy grid that is feeding old inefficient buildings and houses or a lean, intelligent system focused on efficiency and minimizing consumption. Answering these questions is not simple because of the size and complexity of Ontario's energy grid. In addition, the energy grid is in a state of flux, changing on a regular basis. This continuous change is mainly due to the IPSP energy efficiency and conservation goals, and the retirement of coal fired generation stations. In a report published by the OPA on the results of EEC measures taken in 2008 indicated success. That is the OPA was able to meet its first target of conserving 1,350 MW of electricity (OPA, 2010). These EEC measures were enacted throughout the province beginning with average consumer, low-income consumers, business, and industry. Table 5 shows a breakdown of all initiatives taken in each sectors to achieve the 1,350 MW goal. It is important to note that most initiatives are focused on consumers and businesses, with one initiative for Low-Income consumers and four for industry. The OPA makes a distinction between initiatives that result in energy savings (reduced overall consumption) or demand savings (reducing demand of electricity momentarily during peak times) (OPA, 2010).

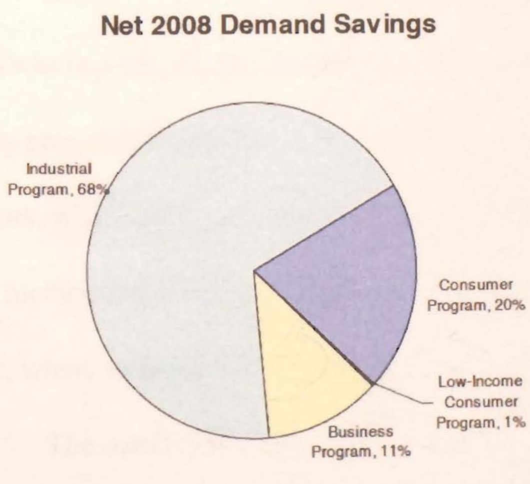
This distinction is crucial when looking at the net proportions each sector has contributed to the 2008 goal. Figure 13 shows the percentages each sectors contributed represented as net demand savings and net energy savings. What this shows is that industrial programs are responsible for the majority of demand saving but have not achieved any real energy savings or efficiency improvements as seen in the second pie chart. The OPA acknowledges that its initiatives for industrial programs were only intended to reduce demand and not affect overall energy consumption. This can be viewed as a weak form of EEC, but it is understandable and does improve the flexibility of the grid contributing to the goal of a 'smart grid'.

What is more pressing is the lack of performance from the business programs, which the OPA attributes to the economic downturn experienced over the last two years. Although this is understandable, given the capital investment EEC measures require. However, It ultimately speaks to the structure of most initiatives being voluntary or optional. It is the unfortunate nature of EEC options that require short-term capital investments yielding long-term savings. In an economic downturn when budgets are stressed the last thing a business is concerned about is a voluntary or optional expense.

The OPA does have a conservation fund that funded 15 projects from 2008 - 2010. The fund mainly supports development and education of EEC initiatives. The OPA invested $3

Table 5: OPA 2008 Conservation Portfolio

Program	Target Market	2008 Conservation Initiatives
Consumer	Residential households	▪ Free pickup of old, working, inefficient appliances ▪ Rebates on high-efficiency, replacement cooling and heating systems ▪ In-store coupons on energy-efficient products ▪ Direct load-control devices for air conditioning and electric water heaters ▪ Contest to encourage summer electricity conservation ▪ Aboriginal retrofit pilot (five communities) ▪ Clothesline giveaways, holiday light exchanges (Toronto only) ▪ Incentives for retrofit (lighting, motors and HVAC) of multi-family buildings ▪ Renewable Energy Standard Offer Program (RESOP)
Low-Income Consumer	Low-income residential households	▪ Free compact fluorescent light bulbs (Toronto only)
Business	Commercial/ institutional facilities	▪ Incentives for retrofit (lighting, motors and HVAC) of existing buildings ▪ Incentives for energy-efficient new construction ▪ Direct load-control devices for air conditioning and electric water heaters for small commercial businesses ▪ Voluntary load shedding (DR1) ▪ Contractual load shedding (DR3) ▪ Incentives for peak shedding (Hydro One only) ▪ Customer-based generation (RESOP, and combined heat and power)
Industrial	Industrial facilities	▪ Voluntary load shedding (DR1) ▪ Contractual load shedding (DR3) ▪ Incentives for peak shedding (Hydro One only) ▪ Customer-based generation (RESOP, and combined heat and power)



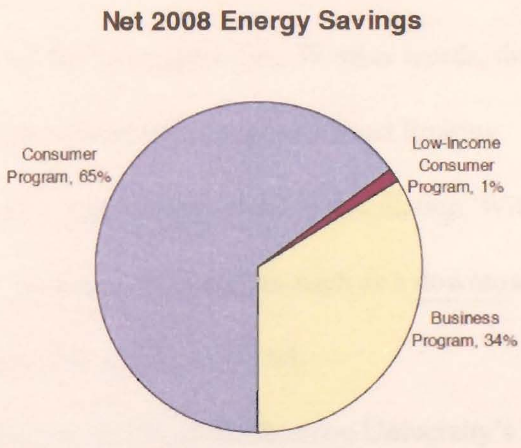


Figure 13: Breakdown of 2008 OPA Portfolio Savings by Program

million of the total $6.7 million project cost. This does seem like a fair sum of money; however, when considering the $7 billion dollars committed to developing a renewable energy manufacturing base in the province the $6.7 million seems insignificant. In addition, this fund does not directly support EEC initiatives which may explain the lack luster performance of the business sector.

It seems that the OPA is working towards EEC yet when the numbers are presented it is clear what is more important - supply. The OPA and government at large are more interested in creating renewable supply over investing in EEC. Although this may not be prudent based on the provinces impending supply shortage it would seem understandable to be building new supply. However, as mentioned above the impact of EEC measures may alter the quantity of supply needed over the next 25 years. The IESO has already noted a steady decline in demand over the past two years as noted in the annual outlook report. The IESO attribute this to the OPA meeting its conservation targets and general energy efficiency improvements and conservation and economic slowdown in the manufacturing sector (IESO, 2009).

6.Conclusion

The goal of this research was to develop and implement a workflow that was able to estimate the solar photovoltaic potential of building rooftops and facades. Overall the workflow was a success, in that both the research question and objectives were met. In particular, the chosen software tools were able to create and analyze a scaled 3-D building model to determine the best possible areas to locate PV arrays, and yield an estimation of yearly electricity output. With this information it is possible to calculate a relatively accurate EROI to determine financial feasibility.

Although this research was successful it revealed some unexpected and undesirable results. The first issue is the amount of rooftops that were already occupied by either HVAC systems, skylights or greenroofs and therefore unsuitable for solar PV applications. The second limiting factor was the degree of overshadowing on surfaces, greatly reducing the possible areas for locating solar PV. Since, the purpose of the SAA was to account for overshadowing, the end results in some cases were slightly discouraging but somewhat expected.

Nonetheless, it is important to note that the workflow was successful, and that the study area was in a densely populated urban area, making up the downtown core. In other words, the study area was an extreme case with some of the worst possible building mixes and limiting factors, which ultimately speaks to the need for an SAA prior to any solar PV installation. With this methodology it is now possible to determine in extreme environments, such as a downtown core, where to locate solar arrays and how much electricity can be expected.

The combined estimation amounted to approximately 5% of the Ryerson University's yearly electricity consumption. This was less than the expected; however, when considering the extent of overshadowing, on some rooftops and walls 5% is reasonable. As discussed above this also speaks to limitation with current solar PV technology and the need for energy efficiency and conservation measures. Since, it is much easier to improve overall energy use and even the output of a PV panel than it is to find more places to locate solar arrays in urban regions, according the SAA.

The next logical evolution of this research would be to produce more time sensitive data that could be used to help manage the flow of electricity from solar PV arrays. In particular, hourly and 10-minute data would be needed to allow the IESO to properly manage the flow of electricity. This would provide an accurate prediction of the expected electricity output based on the yearly average for each day of the year. Ideally, this information would be made available in real-time as opposed to average estimations for any given day of the year.

With the level of functionality demonstrated in this research and the potential for further development, the issues of intermittence, or poor performance of solar PV as a renewable energy source can be significantly reduced, if not eliminated. Locating solar PV arrays in the best possible location maximizes solar exposure and ultimately electricity generation. With the eventual evolution of this type of analysis, yielding more time sensitive and possibly real-time data, solar PV will eventually reach seamless integration into both building design and the energy grid at large.

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8.Appendix: Facts and Figures

A. Data Release Form

TORONTO

Agreement/Release of *Digital Mapping, Graphic or Tabular Data*

Applicants Name and Company:

Company Name	**Ryerson University**
Full mailing address	**350 Victoria St.** **Toronto, ON M5B 2K3**
Telephone Number	**(416) 979-5000, ext. 7777**
Fax Number	
Email address	**david.forgione@ryerson.ca**

Attention: **David Forgione**

1. Digital Mapping Data Requested:

files size
format

Description of digital data...(the "Data")
3D data/Mapping/Images
boundaries for data
North – **Carlton St.**
South – **Dundas St. E**
East – **Jarvis St.**
West – **Young St.**
or description

2. Fee Structure:

The fee for the Data herein is	00.00
Labour and/or Processing charge	00.00
GST #86740 2299 RT0001 6%	00.00
Total	**00.00**

In consideration of the Corporation of the City of Toronto, hereinafter called the City, providing to the Data to COMPANY NAME (the "Applicant"), the Applicant hereby, releases, remises and forever discharges the City, its successors and assigns from *any* and of all manner of actions, causes of actions, debts, claims and demands whatsoever which against the said City the Applicant ever had or which the Applicants heirs, executors, administrators or assigns or any of the hereinafter can, shall or may have for or by reason of the use or otherwise of the above-noted Data provided by the City to the Applicant and the Applicant will from time to time thereafter well and truly save, defend, save harmless and fully indemnify the City from and against all claims and demands which may be brought against or made upon the City and against all loss, cost and damage which the City may sustain, suffer or be put to in any way incidental to providing the Data to the Applicant.

The Data is protected by copyright of which the City is the sole owner. The Applicant acknowledges and agrees that the Applicant is granted only a non-exclusive, restricted license to use the Data for the Applicant's own internal business purposes. The Applicant may not reproduce, modify or alter the Data by any means for any purpose other than the Applicant's own internal business purposes without the prior written consent of the City. *The Applicant shall use the Data only for the following internal business business purpose as deescribed below, and for no other purpose whatsoever and shall ensure that all of its employees and agents comply with this condition:*

This data will be used in a computer model designed to estimate solar energy potential of buildings in urban regions. The model is the main component of a masters thesis project.

The Data, or any portion of the Data, shall not be sold, licensed or otherwise transferred by the Applicant to any third parties either voluntarily or by operation of law. This agreement may not be assigned by the Applicant without the prior written consent of the City, which consent shall not be unreasonably withheld.

The Applicant acknowledges and agrees that the City makes no warranties with respect to the Data provided under this Agreement as to content, completeness, accuracy, merchantable quality, or fitness for a particular purpose, express or implied, or arising by law or by statute, or by usage of trade or course of dealing. The entire risk as to the results and performance of the City's Data is assumed by the Applicant and the City shall have no liability for reliance placed upon the Data by the Applicant or any other person or entity.

THE APPLICANT	City of Toronto
[signature]	....
Name	Carolyn Humphreys *for* *City Planning*

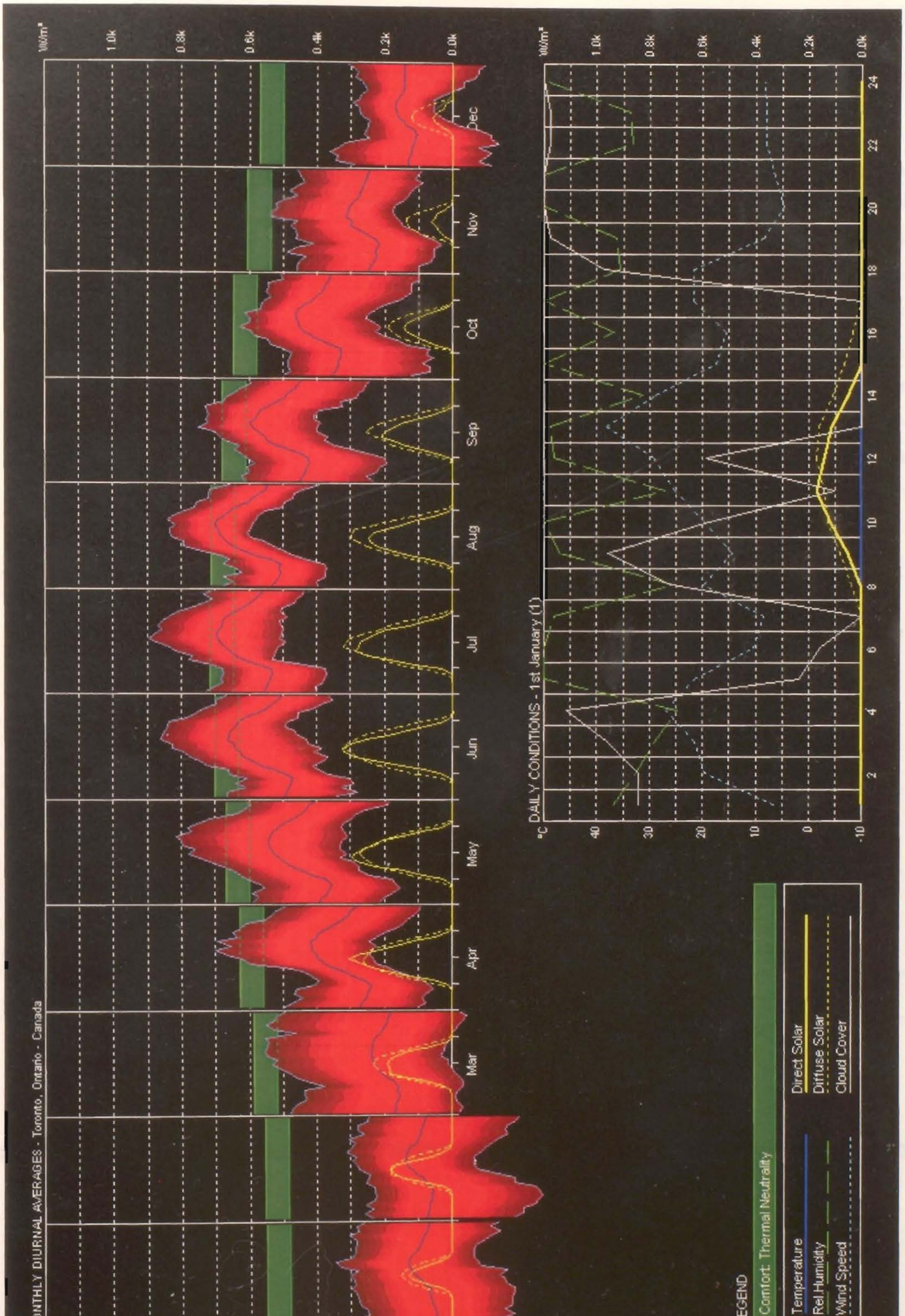
June 16, 2009
Date

Masters Student
Title:

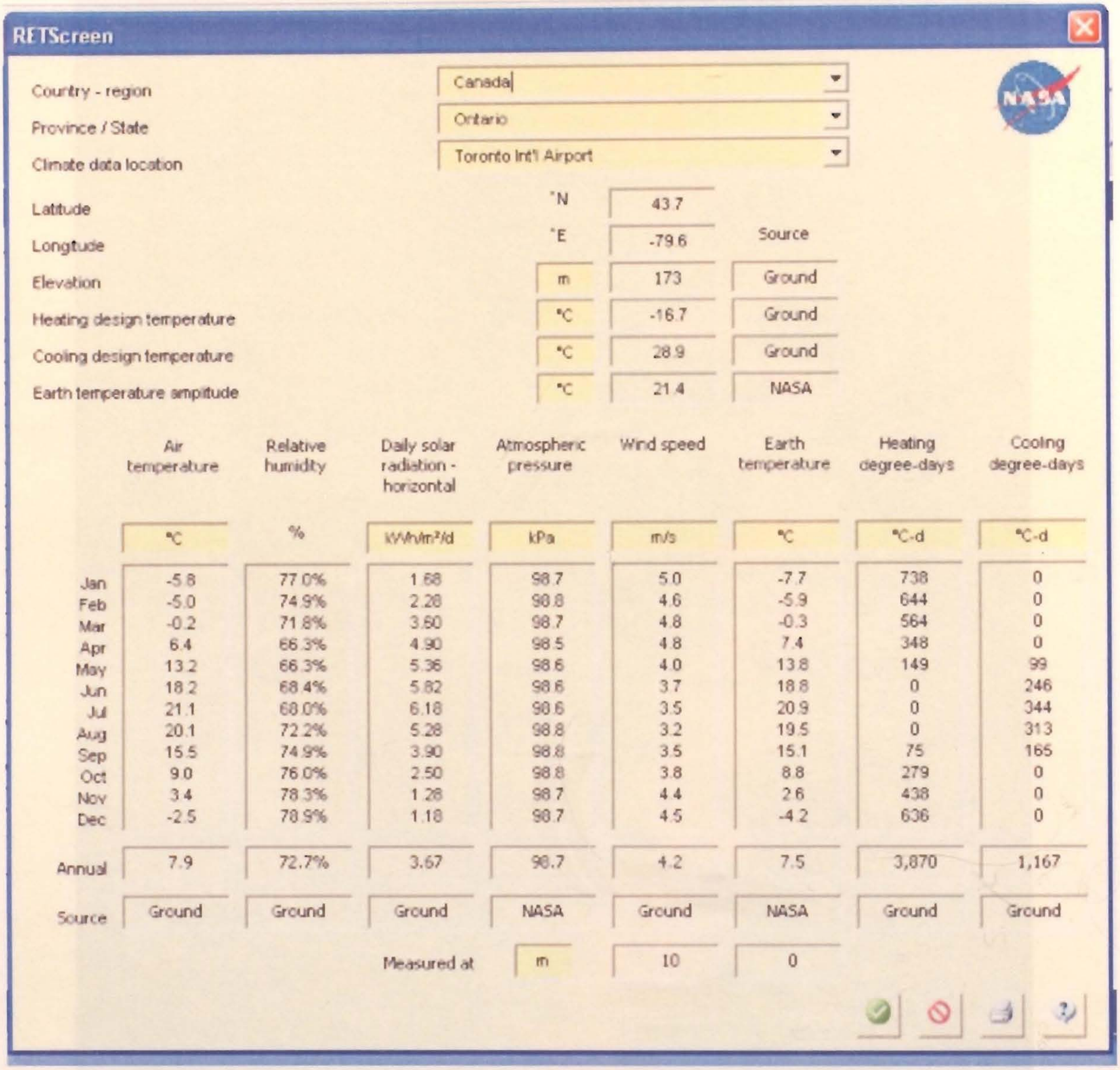
....
Date

Program Manager
Title:
19E Toronto City Hall
Toronto, Ontario
M5H 2N2
(416)392-1536 tel
(416)392-1744 fax
chump@toronto.ca

B.Ecotect Weather Data



C. RETScreen Weather Data



RETScreen

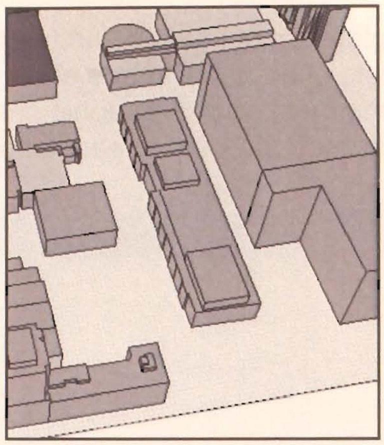
Country - region		Canada	
Province / State		Ontario	
Climate data location		Toronto Int'l Airport	
Latitude	°N	43.7	
Longitude	°E	-79.6	Source
Elevation	m	173	Ground
Heating design temperature	°C	-16.7	Ground
Cooling design temperature	°C	28.9	Ground
Earth temperature amplitude	°C	21.4	NASA

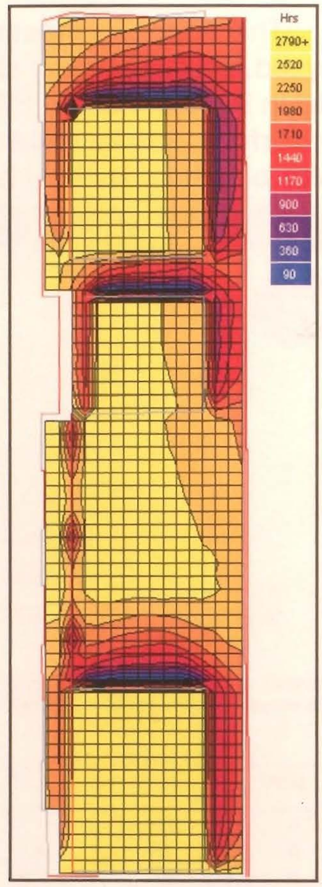
	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
Jan	-5.8	77.0%	1.68	98.7	5.0	-7.7	738	0
Feb	-5.0	74.9%	2.28	98.8	4.6	-5.9	644	0
Mar	-0.2	71.8%	3.60	98.7	4.8	-0.3	564	0
Apr	6.4	66.3%	4.90	98.5	4.8	7.4	348	0
May	13.2	66.3%	5.36	98.6	4.0	13.8	149	99
Jun	18.2	68.4%	5.82	98.6	3.7	18.8	0	246
Jul	21.1	68.0%	6.18	98.6	3.5	20.9	0	344
Aug	20.1	72.2%	5.28	98.8	3.2	19.5	0	313
Sep	15.5	74.9%	3.90	98.8	3.5	15.1	75	165
Oct	9.0	76.0%	2.50	98.8	3.8	8.8	279	0
Nov	3.4	78.3%	1.28	98.7	4.4	2.6	438	0
Dec	-2.5	78.9%	1.18	98.7	4.5	-4.2	636	0
Annual	7.9	72.7%	3.67	98.7	4.2	7.5	3,870	1,167
Source	Ground	Ground	Ground	NASA	Ground	NASA	Ground	Ground
			Measured at	m	10	0		

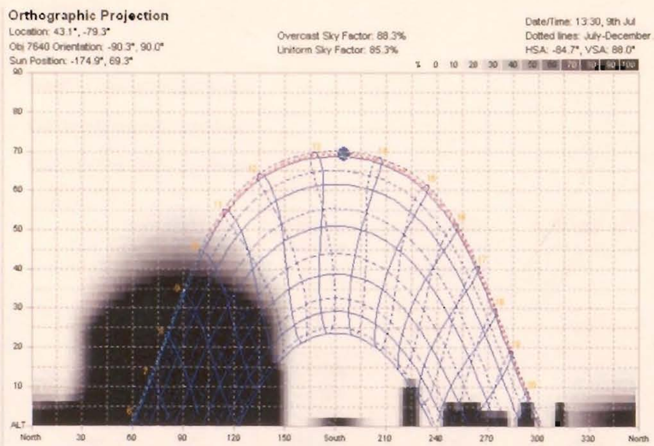
D. Building Summary Sheet and SAA Results

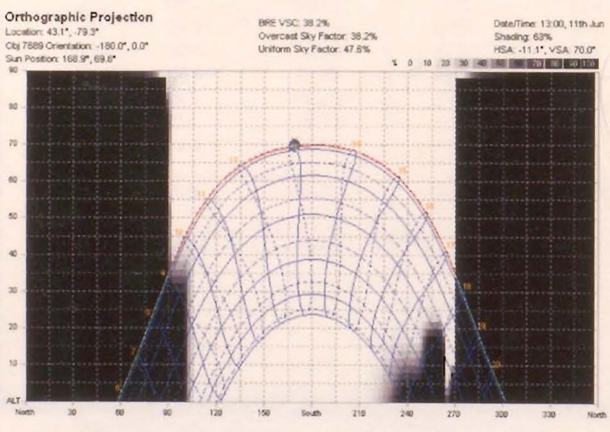
This appendix presents a complete set of images and results for each building analyzed. Each summary sheet consists of an aerial image and the corresponding 3-D model in Ecotec. For the SAA a shading mask in orthographic projection is shown for each surface, one for walls and one for rooftops Next to each shading mask is the SAA results for in total sunlight hours.

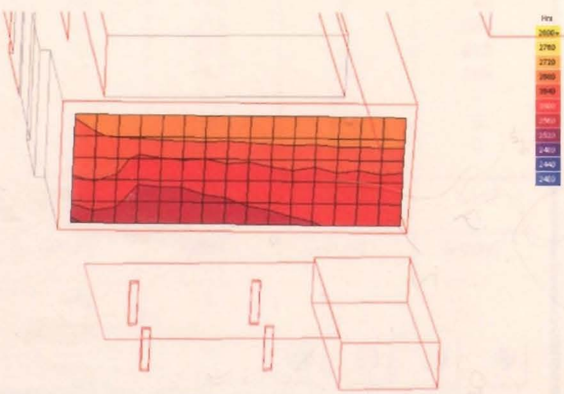
George Vari Engineering and Computer Centre - ENG



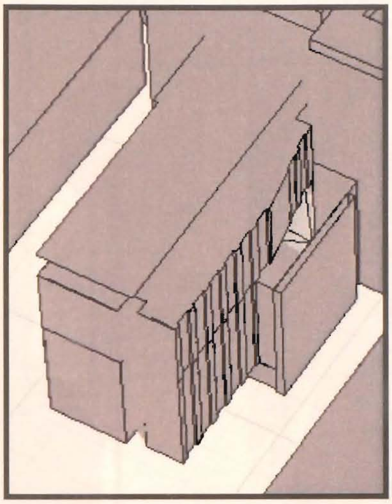


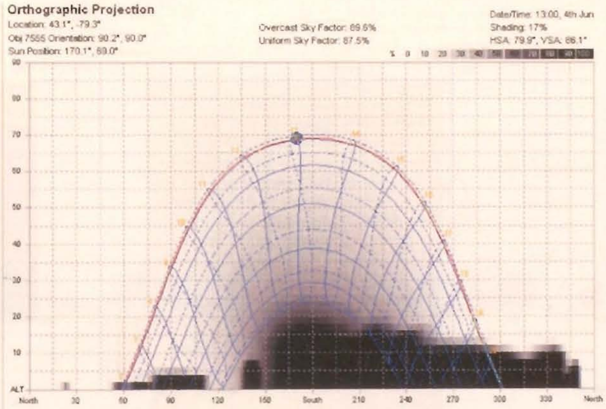


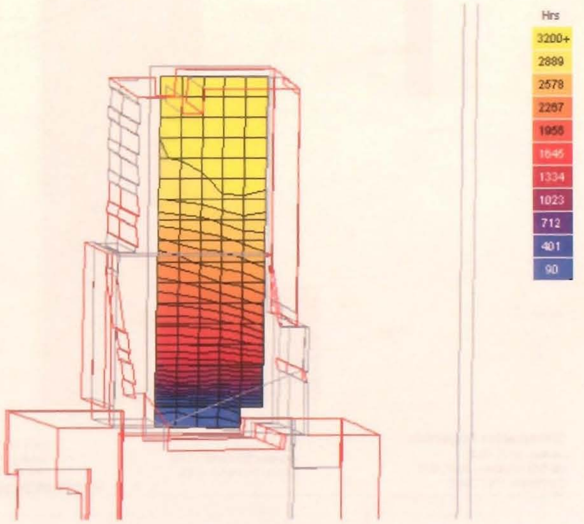




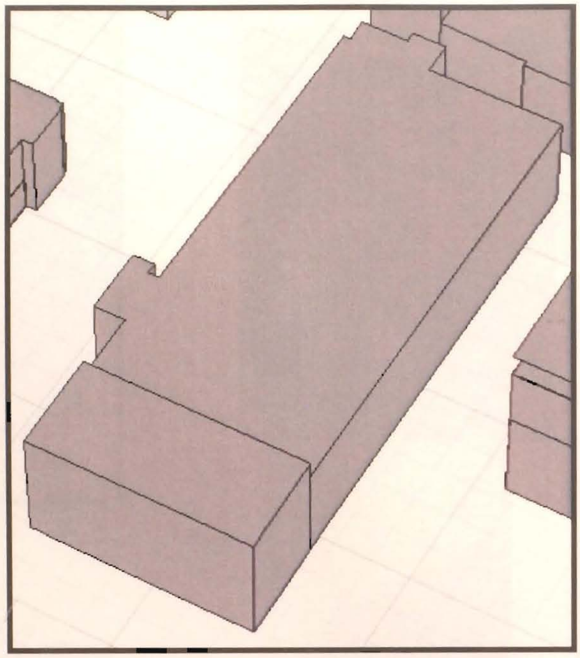
Chang - CED

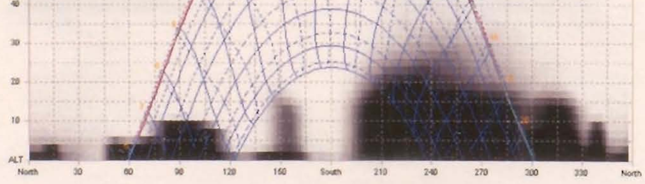


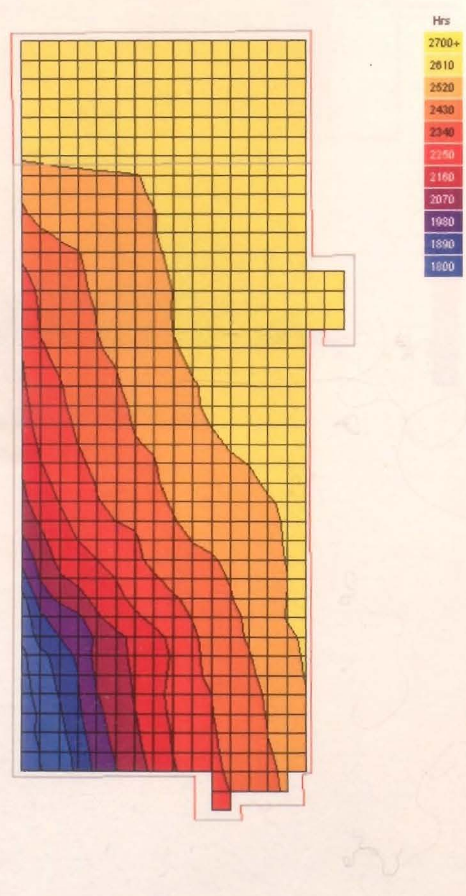

Orthographic Projection
Location: 43.1°, -79.3°
Obj 7555 Orientation: 90.2°, 90.0°
Sun Position: 170.1°, 69.0°
Overcast Sky Factor: 89.6%
Uniform Sky Factor: 87.5%
Date/Time: 13:00, 4th Jun
Shading: 17%
HSA: 79.9°, VSA: 86.1°
North
South
North


Hrs
3200+
2889
2578
2267
1956
1645
1334
1023
712
401
90

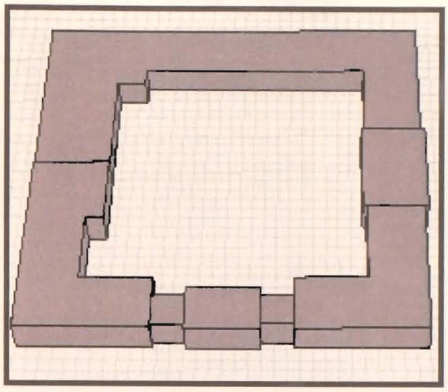
School of Imaging Art - IMA

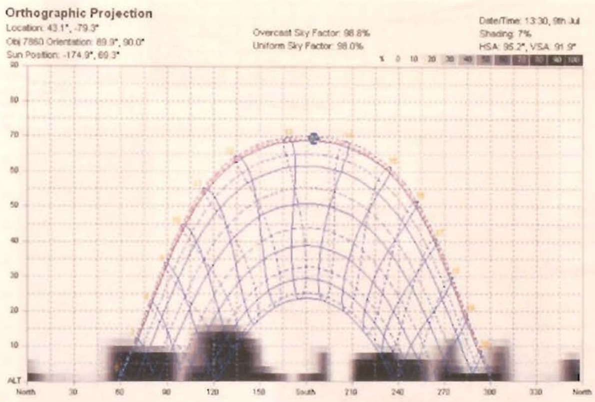


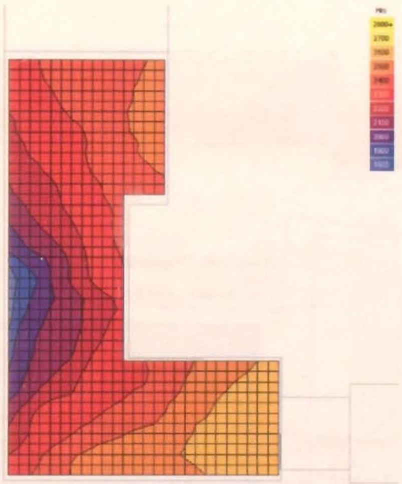


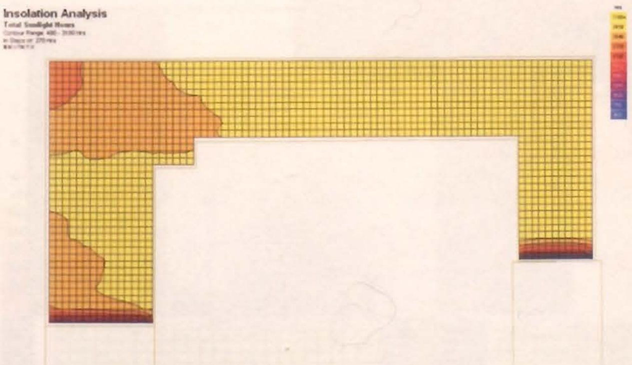


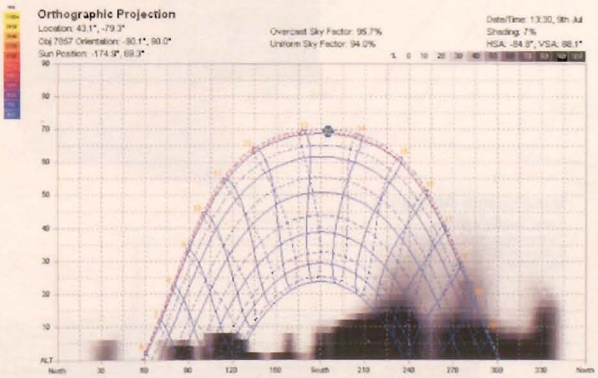
Kerr Hall



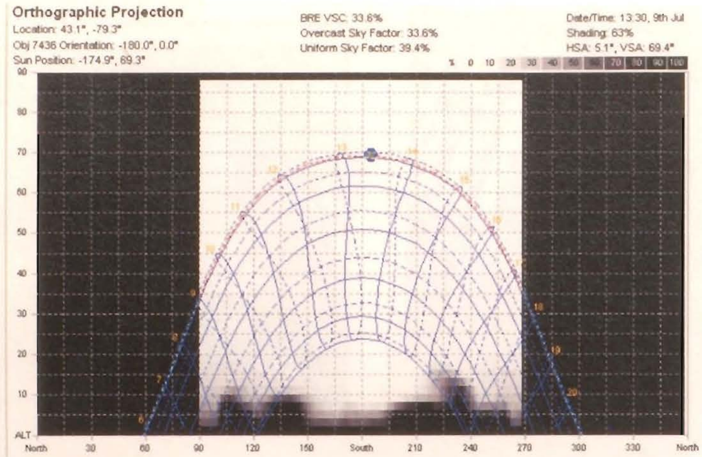

Orthographic Projection
Location: 43.1°, -79.3°
Obj 7860 Orientation: 89.9°, 90.0°
Sun Position: -174.9°, 69.3°
Overcast Sky Factor: 98.8%
Uniform Sky Factor: 98.0%
Date/Time: 13:30, 9th Jul
Shading: 7%
HSA: 95.2°, VSA: 91.9°

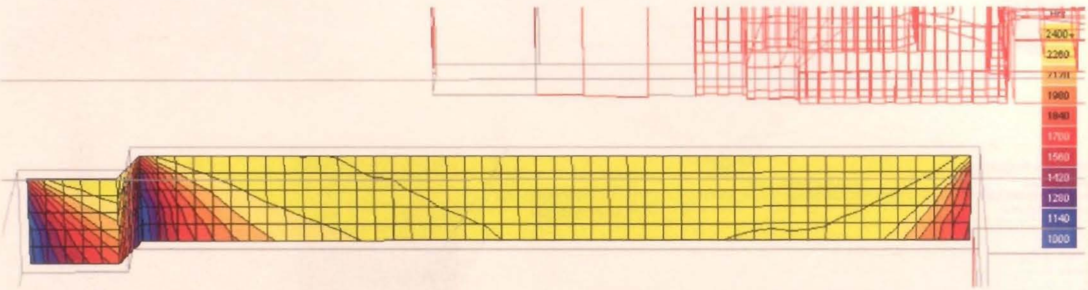


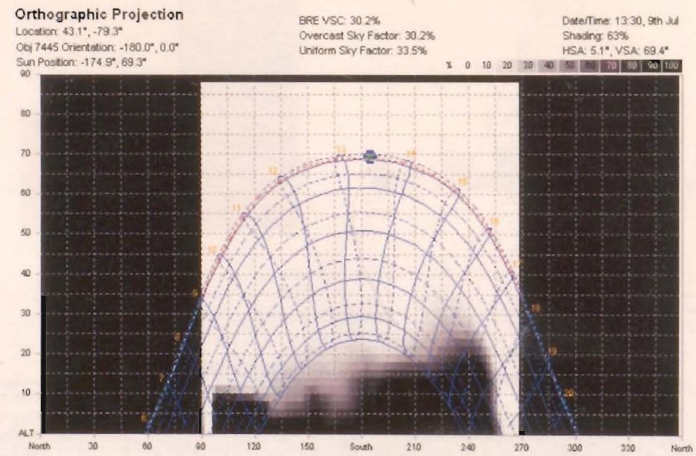

Insolation Analysis
Total Sunlight Hours

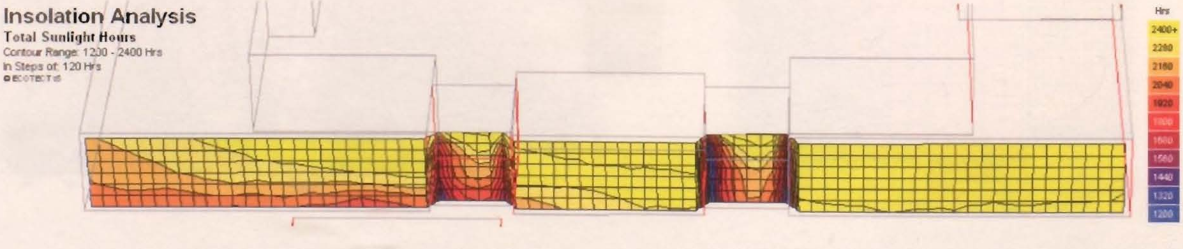

Orthographic Projection
Location: 43.1°, -79.3°
Obj 7857 Orientation: -90.1°, 90.0°
Sun Position: -174.9°, 69.3°
Overcast Sky Factor: 95.7%
Uniform Sky Factor: 94.0%
Date/Time: 13:30, 9th Jul
Shading: 7%
HSA: -84.8°, VSA: 88.1°

Kerr Hall South Walls

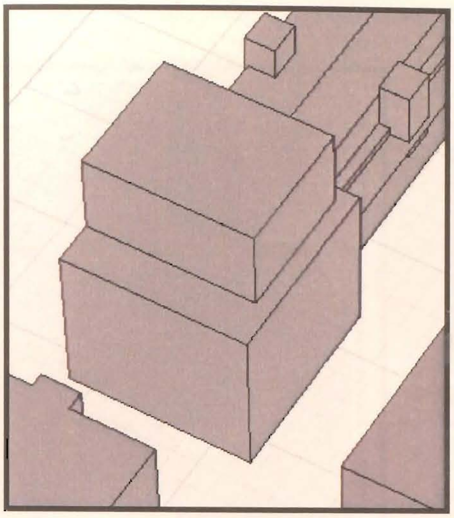


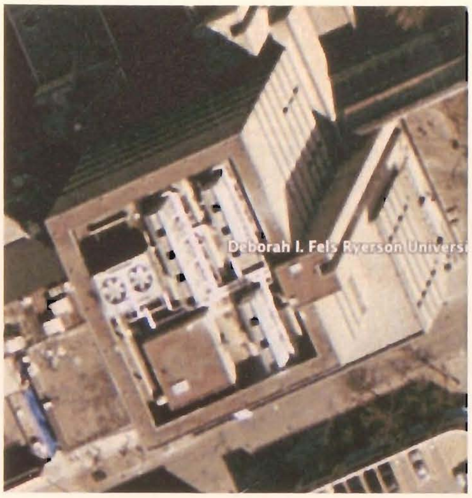


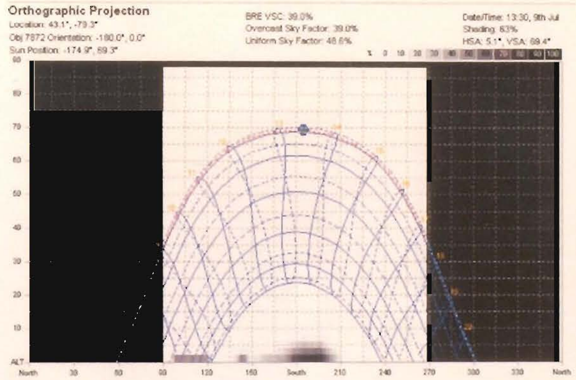


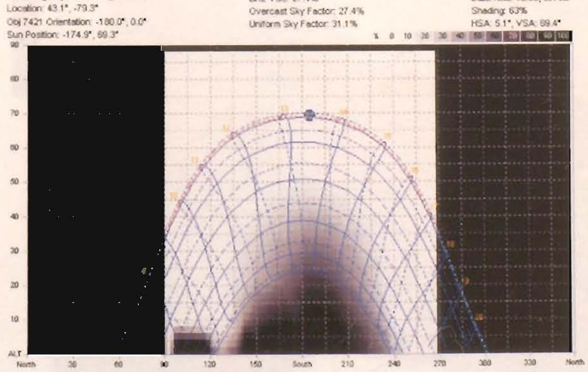


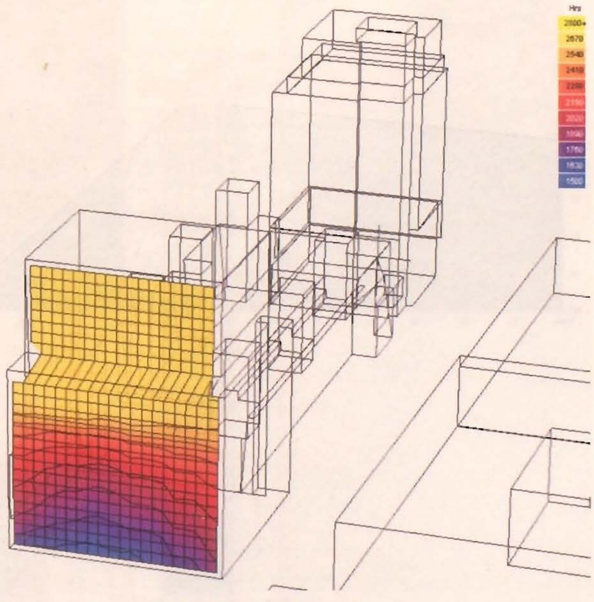
Library Building -LIB



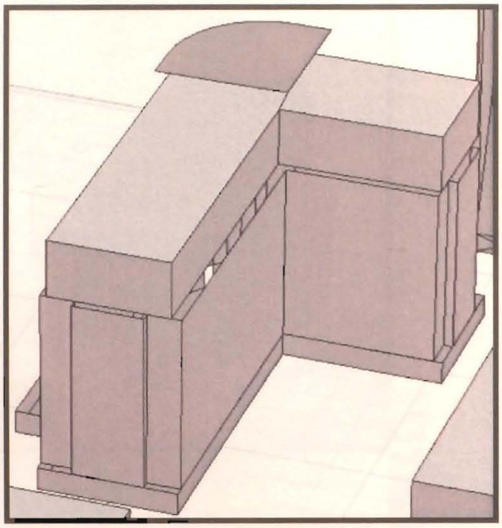


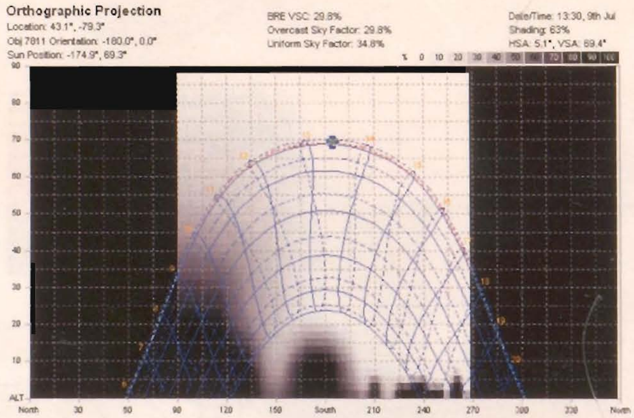


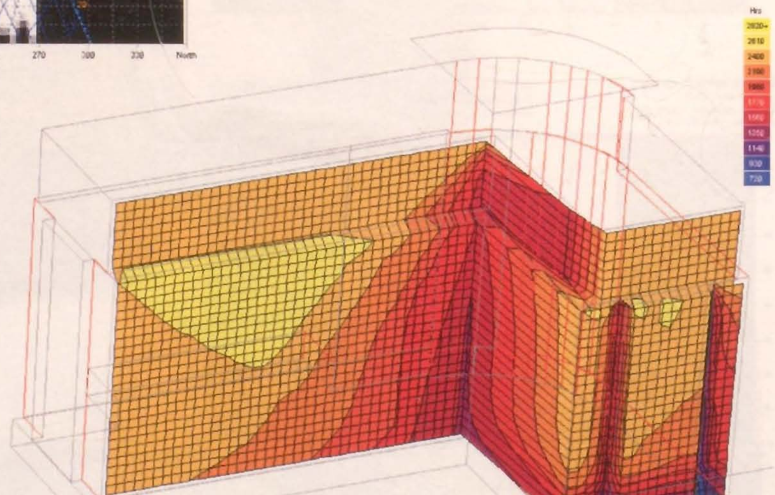




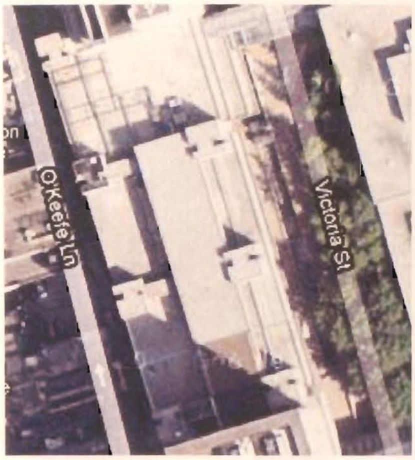
Pitmans Hall - PIT

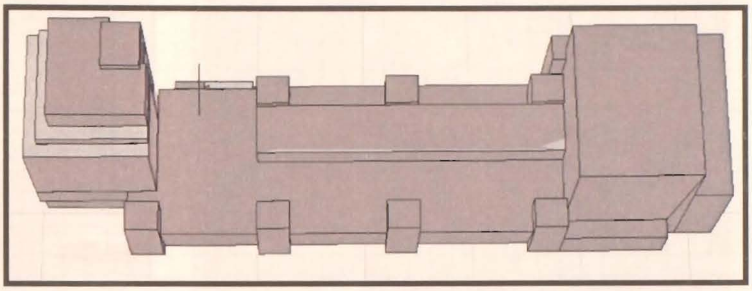


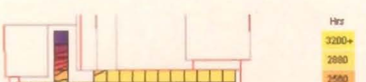


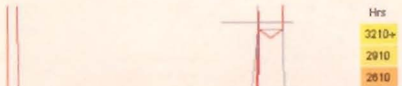


Podium - POD

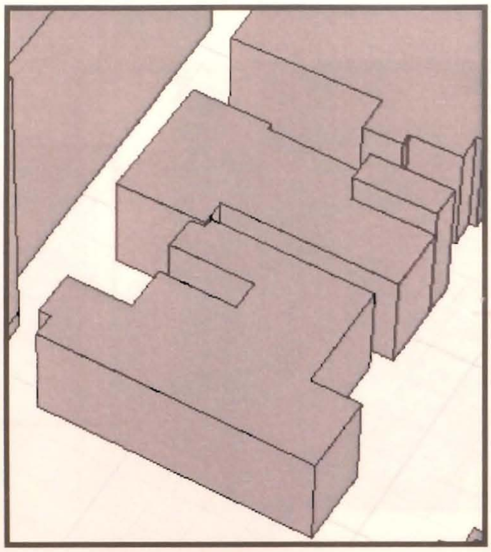

O'Keefe Ln
Victoria St

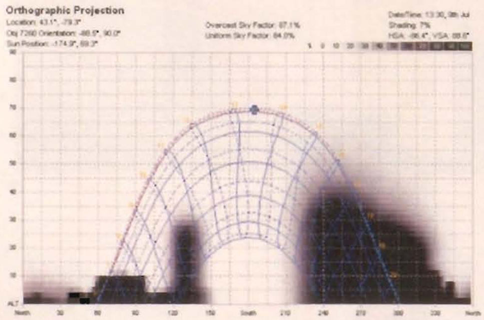


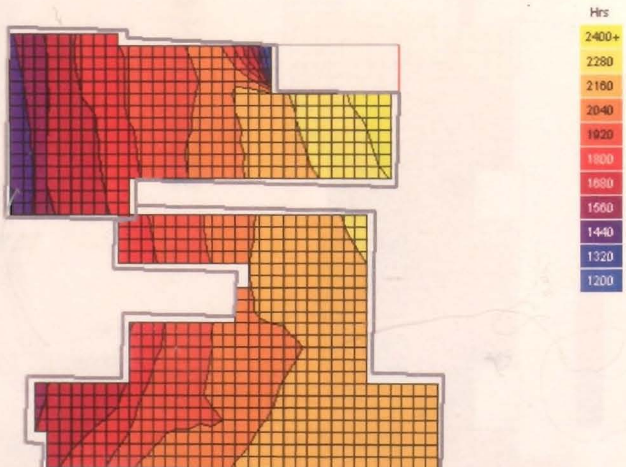

Hrs
3200+
2880
2560
2240
1920
1600
1280
960
640
320
0


Hrs
3210+
2910
2610
2310
2010
1710
1410
1110
810
510
210

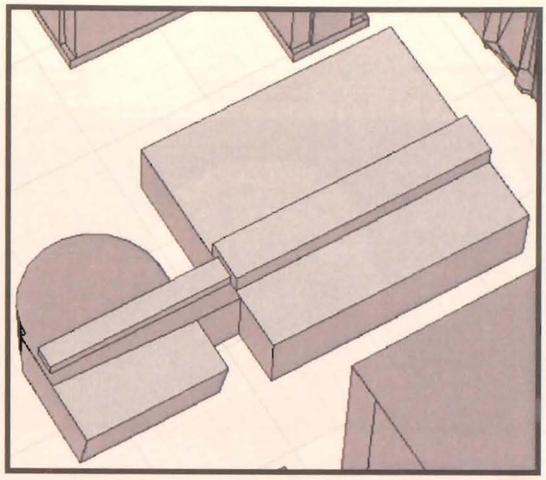
Project Offices - PRD

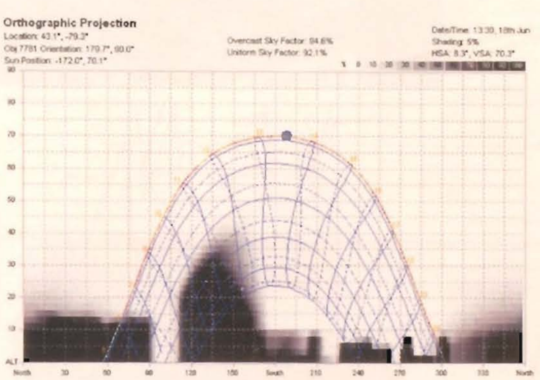


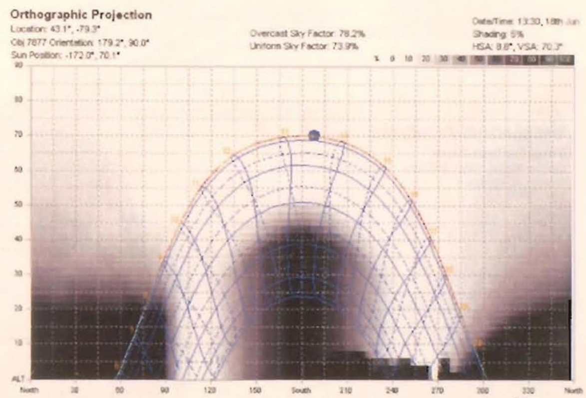


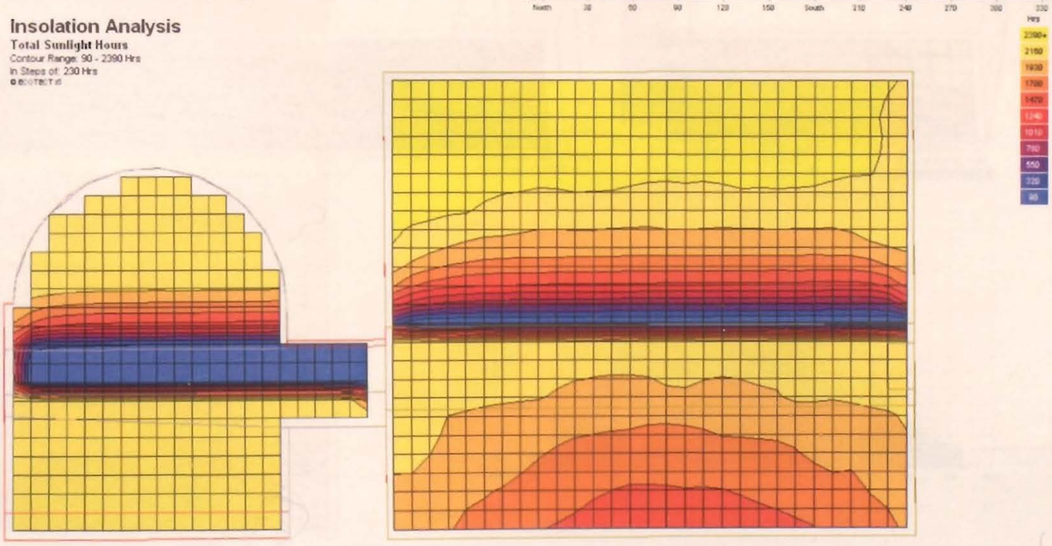


Rogers Communication Centre - RCC

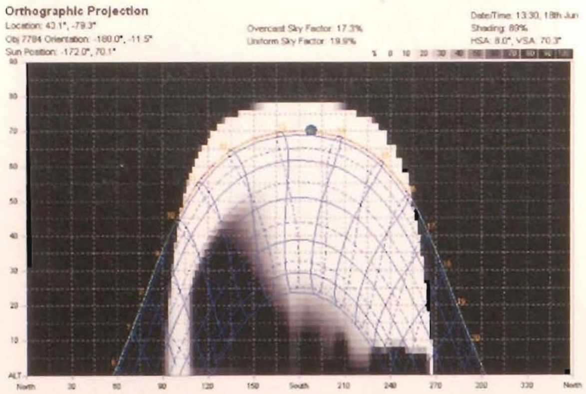




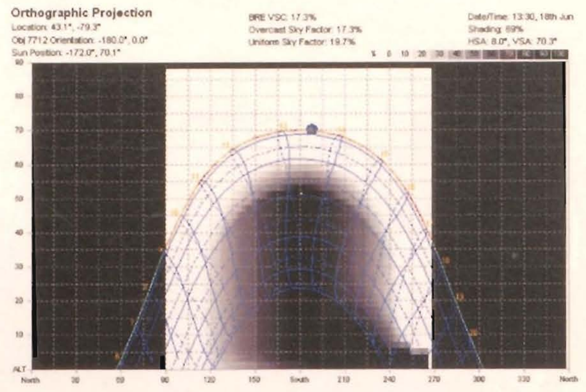




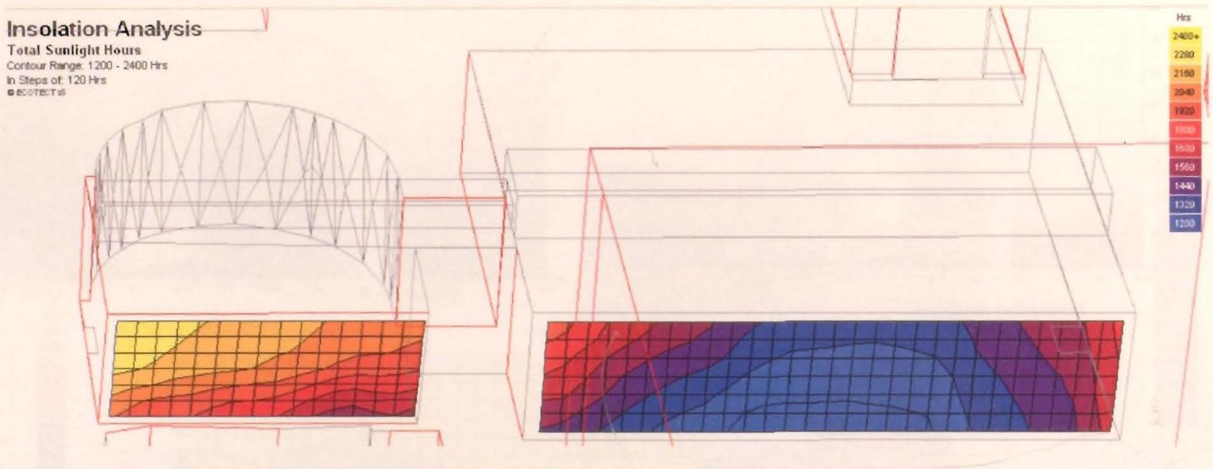
RCC Walls S



Orthographic Projection
Location: 43.1°, -79.3°
Obj 7784 Orientation: -180.0°, -11.5°
Sun Position: -172.0°, 70.1°
Overcast Sky Factor: 17.3%
Uniform Sky Factor: 19.9%
Date/Time: 13:30, 18th Jun
Shading: 89%
HSA: 8.0°, VSA: 70.3°

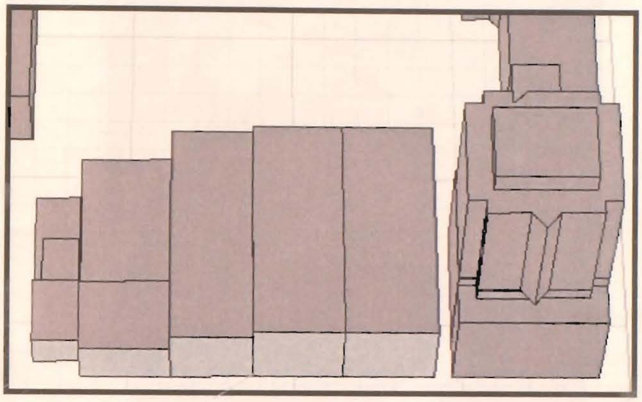


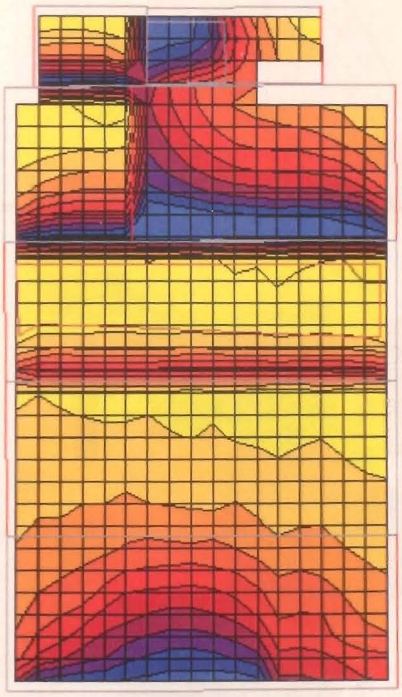
Orthographic Projection
Location: 43.1°, -79.3°
Obj 7712 Orientation: -180.0°, 0.0°
Sun Position: -172.0°, 70.1°
BRE VSC: 17.3%
Overcast Sky Factor: 17.3%
Uniform Sky Factor: 19.7%
Date/Time: 13:30, 18th Jun
Shading: 69%
HSA: 8.0°, VSA: 70.3°

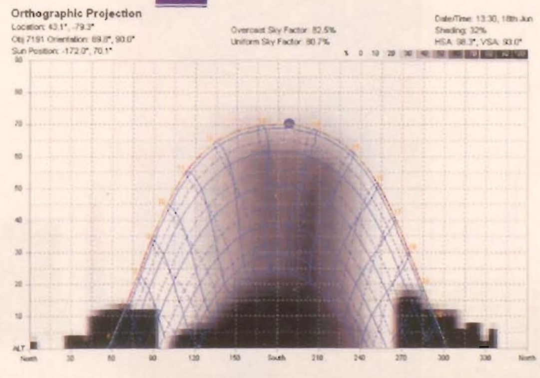


Insolation Analysis
Total Sunlight Hours
Contour Range: 1200 - 2400 Hrs
In Steps of: 120 Hrs
Hrs
2400+
2280
2160
2040
1920
1800
1680
1560
1440
1320
1200

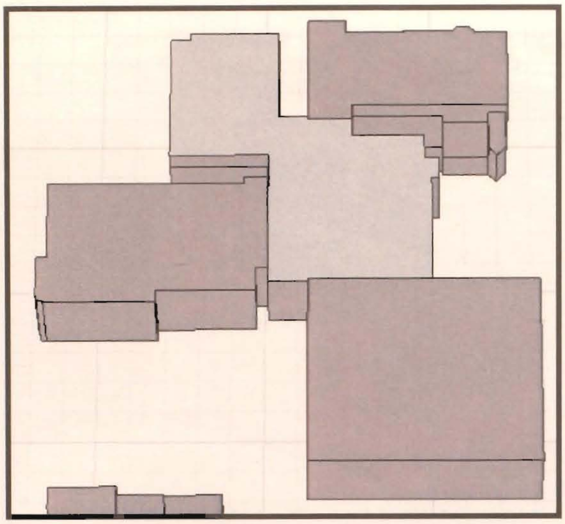
South Bond Building - SBB

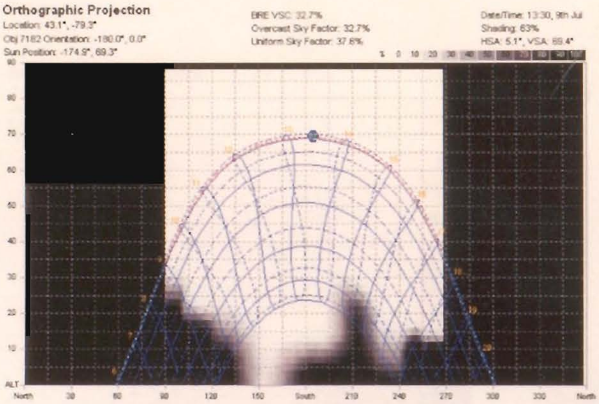


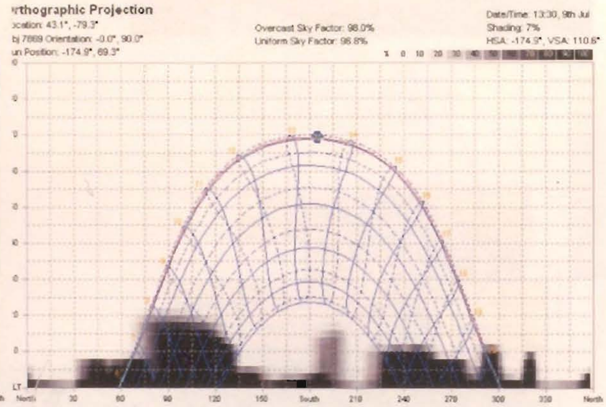


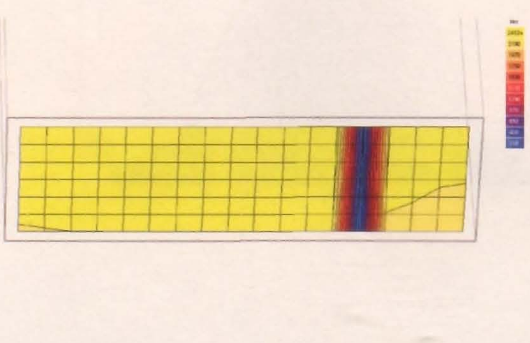


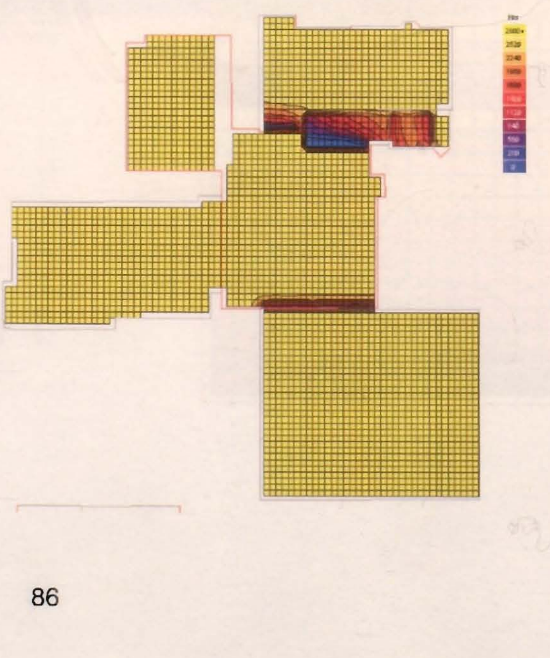
Student Center, Hiedfield Building and Imaging Arts Building











Victoria Building- VIC