This is to certify that the
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AN EXPLORATION OF THE IMPACT OF FIXED SHADING DEVICE GEOMETRY ON BUILDING ENERGY PERFORMANCE

presented by

ALESSANDRO ORSI

has been accepted towards fulfillment
of the requirements for the

Master of Science degree in Construction Management

Major Professor's Signature

5/8/2009

Date

AN EXPLORATION O

ON

AN EXPLORATION OF THE IMPACT OF FIXED SHADING DEVICE GEOMETRY ON BUILDING ENERGY PERFORMANCE.

By

Alessandro Orsi

A THESIS

Submitted to
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in partial fulfillment of the requirements
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Construction Management

2009

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ABSTRACT

AN EXPLORATION OF THE IMPACT OF FIXED SHADING DEVICE GEOMETRY ON BUILDING ENERGY PERFORMANCE.

By

Alessandro Orsi

Building systems account for 71% of energy used in buildings (USGBC). Researchers have explored solutions for reducing energy use in buildings. One way to minimize energy use is by reducing cooling loads through use of shading devices. This research explored the impact of fixed shading device geometry on energy. The research examined the role of shading device geometry including projection, width and height above window in reducing energy use. Researchers used Carrier HAP software, applied to a case study project in Northern Italy to conduct energy analyses. Researchers developed a single space model studying 376 shading device geometries on four different window configurations. A total of 1504 simulations were run in order to select an optimum for the case study. The optimum shading device was applied to a whole building analysis to determine impact on an entire building against a baseline case without shading devices. In order to help test the results researchers ran simulations in three additional locations including Spain, Italy and Germany. The study showed that fixed shading devices have a positive impact on improving building energy performance, particularly on reducing cooling loads. Negative impacts that shading devices may have on energy use in heating months can be more than offset by cooling season savings. Effectiveness of shading devices is closely related to window configuration and building thermal mass. Recommendations are made regarding use and geometry of shading devices.

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– CHAPTER 1 –

INTRODUCTION

1.1 Overview

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1.1 Overview

As the world energy crisis becomes apparent it is increasingly important to consider energy use in buildings. According to the US Department of Energy, buildings account for 40% of total energy consumed in the U.S. 72% of total U.S. electrical consumption, 55% of natural gas and 8% of oil is consumed by or in buildings (Buildings Energy Data Book – 02/03/2008). Building systems including space heating, lighting, space cooling, water heating, building electronics and refrigeration account for 71% of building energy consumption. Nearly 63% of carbon dioxide emissions caused by building end use are attributable to space heating, lighting, cooling and water heating (Buildings Energy Data Book – 02/03/2008).

Because of the impact of buildings on energy consumption, a number of researchers have explored a variety of solutions for reducing energy consumption in buildings. Recently designers have placed emphasis on sustainability and specifically on the LEED® (Leadership in Energy and Environmental Design) standards developed by the U.S. Green Building Council (USGBC) which encourage energy reduction, as well as, indoor environmental quality for building occupants. LEED® has had a significant impact on changing the construction environment as evidenced by its rapid growth throughout the United States and world. Technical requirements of LEED® impacting this research are described in section 2.5. LEED® standards encourage the use of daylight within spaces to create a connection from inside to outside for building occupants (Refer to Appendix A for discussion of LEED)®. Expanding day-lighting is a two sided sword however, as

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expanding unprotected glass areas can also allow for solar heat gain and increased cooling loads, as well as winter heat loss.

One way to minimize cooling loads from expanded areas of glass is through the use of shading to shield glass which is exposed to direct sunlight. Shading devices are rooted in architectural history and many traditional building archetypes have used shading as an environmental response to solar gain. Shading devices impact building energy and day-lighting by reducing solar gain and cooling loads. There are a number of shading solutions including simple fixed shading devices, to more sophisticated solutions such as, between-glass, behind-blinds, high performance glass and moveable shades. This research thesis is focused on fixed shading devices and explores the impact or their geometry on total building energy.

Some previous research has addressed shading devices. A study by Olbina entitled "Decision-making Framework for the Selection and Design of Shading Devices" (Olbina – 2005) explored a number of shading device options. Other researchers have explored related issues, for example Tzempelikos developed "A Methodology for Integrated Daylight and Thermal Analysis of Buildings" (Tzempelikos – 2005) where the researcher identified parameters that influence daylight and thermal comfort. The Green building Journal has published a model for evaluating the performance of façades. Additionally proprietary literature and software for assessing energy performance and daylighting are available.

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This research was targeted at exploring the impact of fixed shading device geometry on building energy performance. The research examined the role of shading device geometry including projection, width and height above the window on energy performance from this traditional shading solution.

Previous research addressed in the literature examined the impact of a single shading device on energy and lighting performance using single-room analysis. However, literature review to date revealed no recent research using computer simulation for fixed projecting shading devices. Most prior research focused on energy performance resulting from the presence and/or absence of the shading device. Literature review uncovered some prior research using simulation of innovative shading devices such as between-glass, behind-blinds, photovoltaic and movable systems. No research considering the impact of fixed-projecting shading device geometry on whole building performance was found. This research studied the effect of fixed shading device geometry on building energy performance through single space and whole-building simulation.

1.2 Research rationale

Despite the potential of fixed shading devices to impact energy use in buildings and their historic presence, the researcher was not able to find definitive research that analyzed the impact of shading device geometries on whole building performance using simulation methods.

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Olbina reported in her research that, "there are no specific guidelines for architects in the selection of a shading device for a specific building" (Olbina - 2005). This gap in research provided an opportunity for this thesis research to add to the body of knowledge surrounding shading devices by exploring the impact of their geometry and developing guidelines for optimum implementation of fixed shading device solutions.

The researcher chose fixed shading devices because, as concluded in The First Solar Energy Catalog for Michigan, "The most effective shading devices will be those that are inexpensive, easy to operate and maintain and those that block only minimal amounts of heating season radiation" (Fridgen et al, 1982). Fixed shading devices fit well with these parameters and this research helps to address them through simulation to asses their impact.

1.3 Research goals and objectives

The long range goal of this researcher is to reduce energy consumption in the built environment. This research was targeted toward partial fulfillment of this long range goal and has two primary objectives. The first was to identify the optimum shading device geometries that could lead to the best annual energy performance on a single-space energy model basis. The secondary objective was to explore the impact of fixed shading devices on the total annual energy consumption based on a whole-building energy simulation. The following primary activities were planned in fulfilling the objectives presented above.

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- **Exploration of the shading device concepts**

The research began by first investigating existing literature addressing shading device technologies, implementation strategies and availability of products on the market. The main goal of the literature review was to identify information currently available which addressed both the theoretical and applied aspects of shading devices.

- **Choice of a single shading device system**

From the literature, a fixed projecting shading device system was chosen for the following characteristics: simplicity of geometry; feasibility of direct performances calculation without the use of proprietary manufacturer's data; ease of configuration to a specific site and wide range of applicability.

- **Analysis of the shading device performance on the whole-building design**

An hourly simulation program, HAP EII software developed by Carrier, was used to quantify the effects of shading device geometry on energy performance using whole building analysis. As a base step, shading device geometry was first modeled and analyzed using a single-space model in order to identify optimum geometries. Optimums identified from the single space analysis were then incorporated into a whole building analysis of a case study building. The objective of the whole building analysis was to determine their impact on a complete building.

A baseline case-study building, the ARCO School, Arco TN, Italy was used for the simulation. The building had already been designed and its detailed technical information w

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information was available. In order to help generalize and test the conclusions, the analysis was also conducted in several climate and latitudinal zones in southern Europe.

- **Impact of shading device geometry on LEED® energy performance compliance**

  Because of the recent interest in LEED® throughout the construction industry the researcher was interested in considering the results in the context of how shading device geometry influences compliance with LEED® energy performance and daylighting criteria. Therefore, in addition to reporting general conclusions on impact of geometry and development of geometry guidelines, results were also reported relative to their impact on LEED® compliance.

1.4 Scope of the research

The research focuses on shading device geometry in the context of commercial buildings with fixed rectangular windows. Reporting was done on an annual basis considering both heating and cooling seasons and integrated data collected from both the singe-space and whole-building simulations.

In order to test the ability of the conclusions to be generalized, the researcher conducted a limited number of whole-building analysis using several climate zones in southern Europe.

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1.5 Limitations

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1.6 Methodology

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The research led to conclusions about the impact of shading device geometry on energy performance and developed conclusions and guidelines for sizing these devices. Because of the researchers interest in LEED®, results were reported in the context of impact on LEED® NC 2.2 credits EA1 Optimize Energy Performance.

1.5 Limitations

A primary limitation of the research was the use of a single case-study building. Other building conditions and configurations could have led to other possible results and conclusions.

The study was limited to fixed shading devices, it may have been possible that other devices, such as, movable or behind-glass systems could have been more effective or less effective. It was not the objective of the research determining which device is most effective.

1.6 Methodology

Following a literature review targeted toward identifying shading device systems and factors impacting their performance, a single fixed shading device was selected, and a case-study approach was used for energy simulation modeling. Carrier HAP EII software was used for simulation and related analysis.

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Parameters considered for the analysis were: geometry (depth, extension beyond lateral window borders and distance from upper window border), façade orientation (south, east and west) and, to a lesser extent, the geographical location of the building.

Various shading device geometries were first tested using single-space simulations to determine optimum solutions which were later incorporated into the whole-building analysis. This preliminary step of developing the single-space analysis was to predetermine optimum geometries prior to data entry in the whole building analysis. Systems found to be most effective using the single space analysis were explored using the whole building analysis approach. Geometry was differentiated generally in 4 inch increments up to a total of 60 inch projection (depth), 12 inch extension from window ends and 12 inch from the top of the window. A total of 385 single space simulations were conducted to draw conclusions about optimum shading device dimensions.

The case-study building was previously modeled with HAP software without fixed shading devices. This research recreated the whole-building model using fixed shading devices. Resulting energy and daylight performance of the original and modified building were considered in drawing conclusions.

1.7 Deliverables

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1.7 Deliverables and benefits of the research

The research accomplished the following:

- Development of performance reference lists showing the relationship between shading device geometry and energy performances (based on single-space analysis).
- Determination of optimum geometries.
- Development of conclusions regarding the impact of the optimum solutions on a complete building using whole-building analysis.

Upon completion of the analysis the researcher as a secondary effort was also able to consider and draw some conclusions on how fixed shading devices impact ability to obtain LEED Credits EAc1.

1.8 Chapter Summary

This section provides an overview of the scope of the research, its objectives and overall approach. Limitations and potential benefits are also reported. Section Two describes background literature and Section Three provides discussion of the research methodology.

– CHAPTER 2 –

LITERATURE REVIEW

2.1 Introduction.

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2.2 Background

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2.1 Introduction.

Section Two presents the literature review to date and is divided into the following subsections:2.1 Introduction, 2.2 Background on energy performance in buildings, 2.3 Shading and Screening Devices in Buildings Related to Energy Simulation Methods, 2.4 Existing Research and Projects and 2.5 Background on LEED®.

The purpose of the literature review was to identify existing published work related to shading device impact on energy and daylighting building performance and to discover previous work that could be helpful to this research.

Practical applications of shading devices are based on theoretical and formally codified principles such as thermodynamic laws, energy codes and legislation. Some discussion of these principles and standards is included as reference for considering measurement approaches, tests and computer modeling situations.

2.2 Background on energy performance in buildings.

This section addresses some of the background literature on energy issues and how they relate to LEED® requirements. The complexity of the LEED® NC 2.2 "Energy and Atmosphere" chapter necessarily involves a large number of codes, protocols and reference standards that constitute the basis of building energy performance assessment. The primary reference standards are identified and briefly described below.

The need for saving energy in buildings is becoming increasingly important in building design. Project teams and architects are moving in this direction. Energy performance

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requirements are increasingly being defined through standards and codes. The following are important documents that have significant influence on energy performance in buildings: ASHRAE/IESNA Standards 90.1 – 2004, ASHRAE Advanced Energy Design Guide for Small Office Buildings – 2004, Advanced Buildings Benchmark - Version 1.1, Energy Policy Act (EPA) – 1992, International Performance Measurement & Verification Protocol (IPMVP), Center for Resource Solution's Green-e Product Certification Requirements. For example the ASHRAE 90.1 2004 is referenced by LEED® as the required energy standard that must be followed in order to obtain LEED® certification. Additionally, ASHRAE 90.1 is one of the energy codes that HAP EII Carrier program is based on. Standards directly related to this research are briefly described below. More detailed discussion of other documents affecting and related to energy performance in buildings can be found in Appendix B.

ASHRAE/IESNA Standards 90.1 (2004) is important especially for mechanical equipment features and minimum standard requirements. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is an important association that influences this field along with the American National Standard Institute (ANSI). ASHRAE publishes a well recognized series of standards and guidelines relating to HVAC systems and issues. These standards are often referenced in building codes. This thesis research was based on the ASHRAE 90.1 "Energy Standard for Buildings Except Low-Rise Residential Buildings". Although ASHRAE doesn't specifically address daylighting requirements it does have requirements for how computer simulation shall be conducted. ASHRAE 90.1 Chapter eleven "Energy Cost Budget Method" and appendix G "Perfo

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appendix G "Performance Rating Method" were used for this thesis research. (ASHRAE 01 - 03/20/2008).

Advanced Buildings Benchmark - Version 1.1.- is the nationally recognized source that explains how to deliver best-in-class energy efficiency and indoor environmental quality in high-performance commercial buildings. The Benchmark brings together over 30 criteria defining high performance in building envelopes, lighting, HVAC, power systems and controls. Its main use concerns building design and construction fields and helps the project teams gain access to quantitative and descriptive specifications for exceeding state and national minimum standards such as ASHRAE/IESNA Standard 90.1 – 2001 (Advanced Building Benchmark – 03/20/2008). Information contained in this document helped the researcher to optimize the choice of building features and shading devices.

Energy Policy Act – 1992 is a key document related to the core reference standard of this research, the ASHRAE 90.1. The Energy Policy Act (109th Congress H.R.776.ENR, abbreviated as EPACT92) is a United States act. It was passed by Congress to reduce U.S. dependence on imported petroleum by requiring certain fleets to acquire alternative fuel vehicles, which are capable of operating on non-petroleum fuels (Energy Policy Act - 03/20/2008). The provisions developed for improving energy efficiency are summarized as follows:

- *Buildings:* requires states to establish minimum commercial building energy codes and to consider minimum residential codes based on current voluntary codes. This

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- *Utilities:* requires states to consider new regulatory standards that would require utilities to undertake integrated resource planning; allow the energy efficiency programs to be at least as profitable as new supply options; and encourage improvements in supply system efficiency.
- *Equipment Standards:* establishes efficiency standards for: Commercial heating and air-conditioning equipment; electric motors; and lamps.
- *Renewable Energy:* establishes a program for providing federal support on a competitive basis for renewable energy technologies.
- *Alternative Fuels, Electric Vehicles, Electricity:* removes obstacles to wholesale power competition in the Public Utilities Holding Company Act (PUHCA).

International Performance Measurement & Verification Protocol (IPMVP) - Volume III of 2003 – was used to set the measurement parameters of the HAP software in order to execute the whole building analysis and define the research process. Originally funded by the U.S. Department of Energy, IPMVP consists of three volumes. Volume I defines terminology and establishes procedures for determining the savings resulting from retrofits. Volume II focuses on maintaining or improving indoor environmental quality during the implementation of energy-conservation measures. Volume III provides guidance on specific Measurement and Verification (M&V) issues, including applying M&V to renewable-energy systems and to new construction. Additionally, volume III lays out four compliance paths - Options A through D - for different situations assuming a preexisting build

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a preexisting building or system against which performance can be measured. Moreover it introduces ways to establish baseline performance in the absence of a preexisting system or building. Inside the document, Options A and B focus on subsystems, while C and D address whole buildings (Architect International Association – 03/20/2008).

"Center for Resource Solution's Green-e Product Certification Requirements" can be used by project teams that decide to introduce alternative energy sources such as photovoltaic systems. Green-e is defined as the "nation's leading independent consumer protection program for the sale of renewable energy and greenhouse gas reductions in the retail market. Green-e offers certification and verification of renewable energy and greenhouse gas mitigation products" (Green-e – 03/20/2008). Inside this field the Green-e Program defines a certification and verification process for green electricity products that have to meet the following main requirements:

- Exploitation of renewable resources like solar electric, wind, geothermal, biomass and relative source qualification.
- Absence of nuclear power involved in the process.
- Emission criteria for the non-renewable portion of energy supplied.

These criteria provide basic guidelines that can be slightly modified depending on the State or Province of application and, as highlighted for the EPA paragraph, understanding these standards was important in order to have a general view of all credentials related to the LEED® Energy and Atmosphere chapter (LEED NC v. 2.2).

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2.3 Shading & Screening Devices in Buildings.

Shading devices constitute the core of this research work. Architectural solutions and special design strategies for screening and shading devices have been previously studied from many points of view. This research drew from this previous work and applied it to the current thesis.

2.3.1 Engineering articles and technical publications.

A variety of documents were used as reference manuals for the practical aspects of shading devices. Additionally, the literature was used to identify possible benefits and disadvantages. An understanding of how shading devices are used in actual building contexts surfaced from these sources.

"Mechanical and Electrical Equipment for Buildings" (Stein & All – 2006) is a design reference manual that, in section III, reports the main applications of the Illuminating Engineering Society of North America (IESNA) research studies for architectural design and building performance optimization. The lighting chapter is divided into the following subsections which were considered for a preliminary evaluation of the research feasibility:

- Lighting Fundamentals: terminology, definitions, basic characteristics and measurements.
- Light Sources (Daylight and Electric Light): operating characteristics, design features, luminous efficacy.

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- Lighting Design Process: costs issues, power budgets, energy considerations, appropriate illumination provision.
- Daylight Design: passive design solutions, design and analysis.
- Electric Lighting Design: fixture characteristics, calculation techniques, control strategies.
- Electric Lighting Applications: building occupancy, exterior and special lightings.

The "Journal of Green Buildings" published an article in 2006 where the research team developed analysis of Advanced Integrated Façades (AIF) and Double Skin Façades (DSF) in order to validate their high efficiency and to establish performance criteria that could support the design of sustainable façades (Haase & Amato – 2006). In order to achieve this objective, façade performance was characterized into three categories including energy, thermal and visual. The work was based on the simulation analysis of a typical office room, characterized by three different façade-design types. The baseline case consisted of a curtain wall, the second case by an external air curtain and the last one by an internal air curtain, all three cases are graphically represented in figure 2.1 below.

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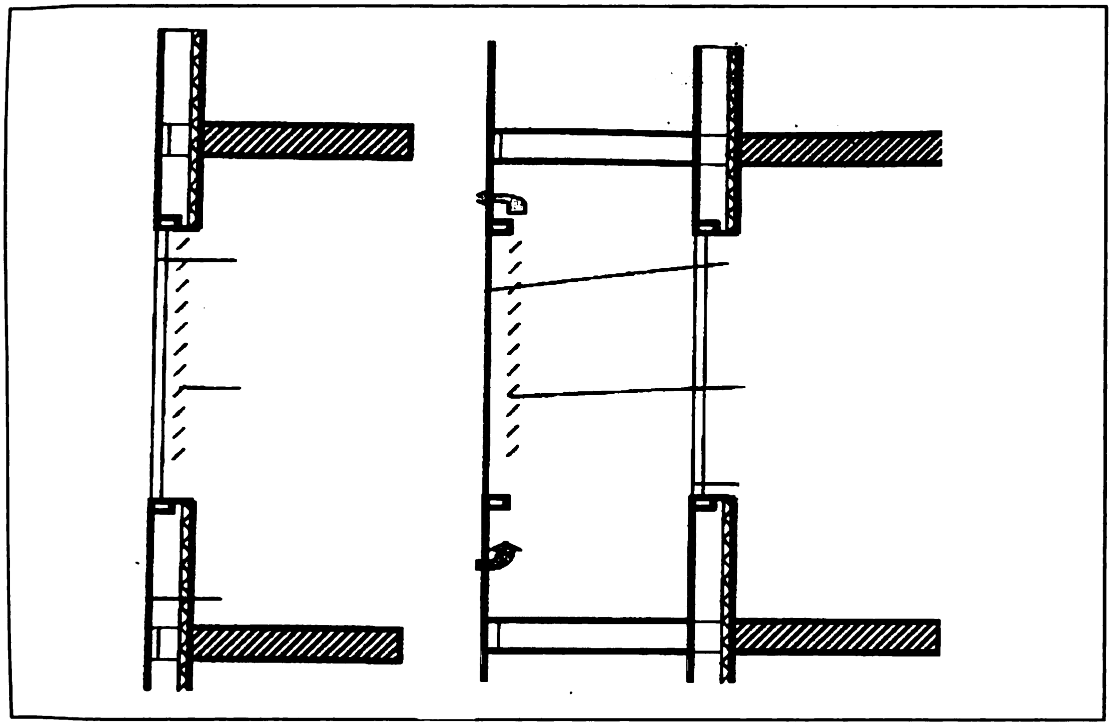

Figure 2.1: Façade details of curtain wall (left), external air curtain (right).

(Haase M, Amato A. – 2006)

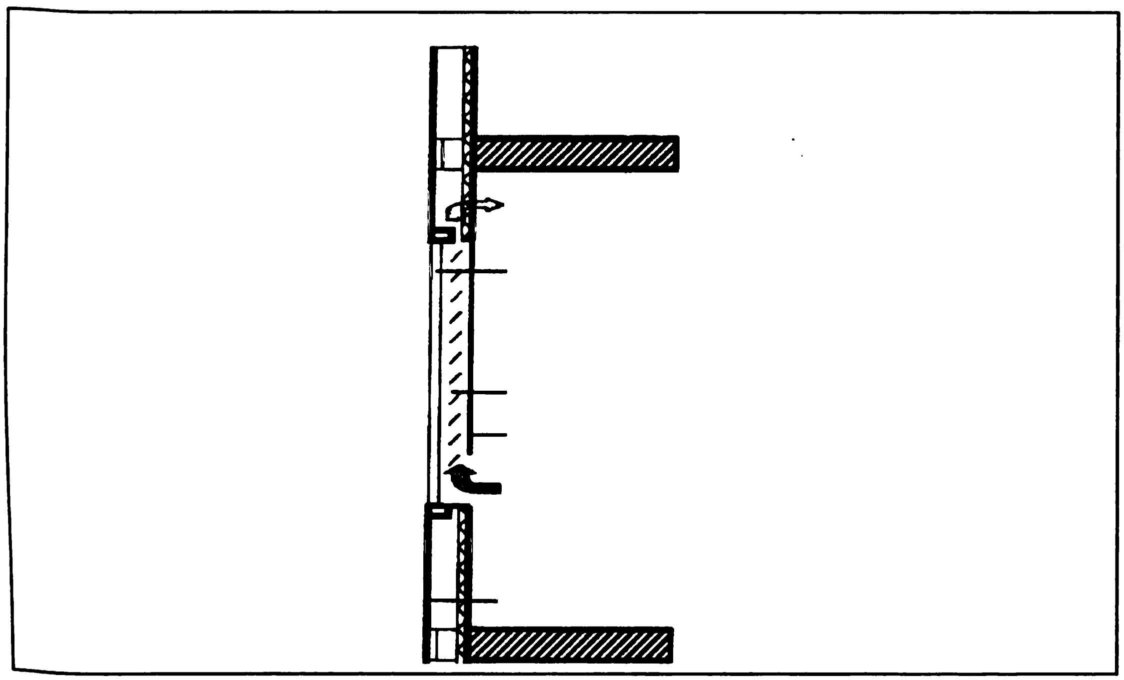

Figure 2.2: Façade details of internal air curtain.

(Haase M, Amato A. – 2006).

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The thermal performance was defined by the following parameters:

- Dry Bulb Temperature
- Mean Radiant Temperature
- Relative Humidity
- Air Velocity
- Metabolic Rate (of occupants)
- Clothing Level (of occupants)

Daylight performance was evaluated using the following parameters, (also implemented in other research articles and dissertations):

- Daylight Factor
- Daylight Coefficient
- Daylight Autonomy

The simulation results showed that optimized window systems using double skin façades (DSF) help to reduce annual energy consumption and improves thermal comfort in the work space. Annual cooling saving for the application of DSF turned out to vary from 11% up to 20% against an average annual cooling energy loss of 5% in the case of normal Air Flow Window without any control strategy. Also daylight analysis results confirmed that implementation of double skin façades improves lighting performance and savings.

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HAP EII software doesn't allow consideration of a double skin-façade as a separate and specific item. All effects of its implementation would have to be input as solar radiation variation, which would had to be calculated separately making the approach used by Haase and Amato unfeasible for this thesis research.

2.3.2 Existing architectural solutions using shading devices.

This subsection identifies available operable systems for shading and screening purposes that could affect the building environment and energy performance. Some investigation of recent work was completed; however, a study of all existing applicable architectural solutions concerning shading and screening devices was not feasible. To reduce the scope of this step an empirical approach based on the existing research work was used, and focused on the primary shading devices where quantitative research had been conducted, and already identified in the literature. Background on shading device solutions are reported and briefly summarized below.

2.3.2.1 Between-glass blinds.

Several products are available on the market under this topic .

- **Unicel Vision Control**: (Vision Control - 04/08/2008). Hollow chambered louvers are sealed between double insulated glass. A primary seal is polyisobutylene that has high resistance to ultraviolet radiation, and the secondary seal was made of polysulfide. The air space between the two panels of glass was dehydrated by desiccant. The air space is 2" wide and louvers are 1 3/8" wide, made of extruded aluminum. Louvers can be installed either ho

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installed either horizontally or vertically. If louvers are wider than 48", a vertical spacer is needed. Blades can rotate 180° and be operated as follows:

- *Manually:* by a hand crank or thumbwheel.
- *Automatically:* by the motor, which can be operated electrically by a programmable logic controller. The timer and sun-sensors can be incorporated in this system.

This particular shading device system is represented in figures 2.3 - 2.4 - 2.5 below.

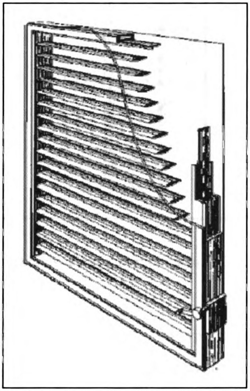

Figure 2.3: Isometric view of horizontal blinds (Vision Control - 04/08/2008)

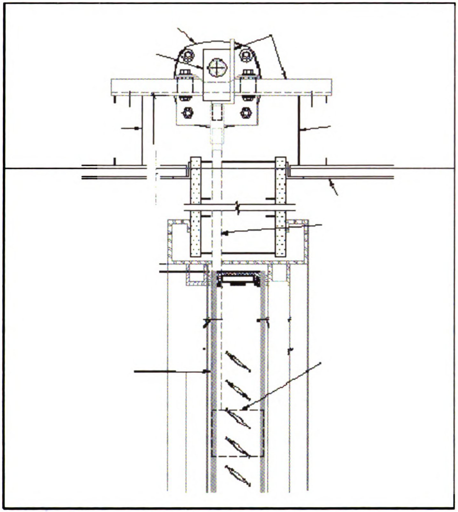

Figure 2.4: Vertical blinds, vertical section (Vision Control - 08/04/2008)

- **Hunter Douglas:** this manufacturer offers two types of between-glass blinds: 5/8. wide and 0.008. thick and 1. wide and 0.006. thick made of aluminum. Blinds can be installed horizontally or vertically. Vertical blinds can be rotated 180°. They can be operated magnetically, using a permanent magnet to move the shading device from a closed position in one direction to a closed position in the opposite direction. This system does not require holes in glass panels (Hunter Douglas – 04/08/2008). Figure 2.6 below represents this type of shading device.

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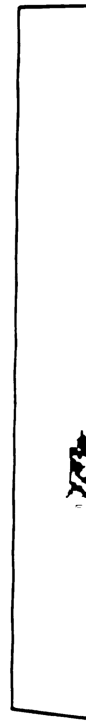
Size Maximums for Between-Glass Blinds				
Min. Air Gap	Slat Width	Max. Blind Width	Max. Blind Height	Max. Area
1 3/8"	1"	96"	96"	40 sq feet

Figure 2.5: Hunter Douglas horizontal blinds standard dimensions.
(Hunter Douglas – 04/08/2008).

- **Concord Shading Systems:** it also offered either motorized horizontal or vertical blinds. Horizontal blinds can be 1" or 2" wide made of wood or aluminum. Vertical blinds are made of PVC or aluminum. The automatic operation of louvers is possible by using a comfort control system that monitors sun radiation intensity by using sunlight-intensity sensor. The control system also moves the shading device depending on sun conditions (Olbina – 2005). Figures 2.6 and 2.7 below shows shading device components.



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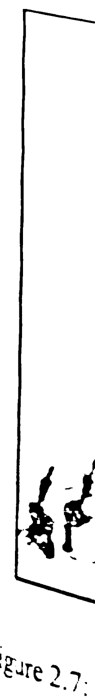

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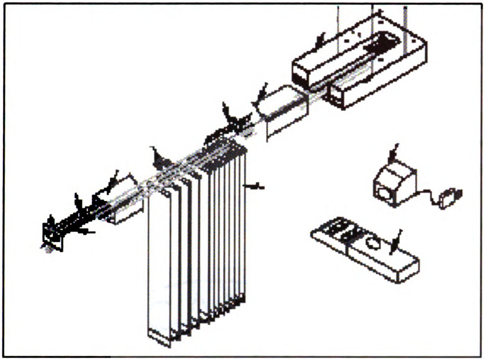

Figure 2.6: Concord vertical blinds device operating scheme, horizontal section (Concord - 04/08/2008).

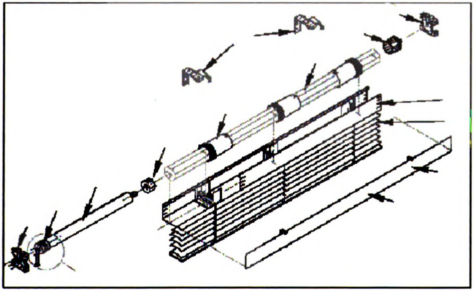

Figure 2.7: Concord horizontal blinds device operating scheme, vertical section (Concord – 04/08/2008).

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- **Photovoltaic shading devices** provide solar control and capture sun energy at the same time. The blinds are fixed between two panes of glass. Adjustable solar blinds are also available. The photovoltaic slats consisted of tandem amorphous silicon cells deposited on glass. Syglam, a German manufacturer, produced two systems, one for roof implementation and the other for vertical façades. A voltage of 24 V was used for stand-alone systems and a voltage of 60 V for the grid-connected system. Nominal power of photovoltaic slats was about 40 W/m^2. Figure 2.8 below provides an example of photovoltaic shading device application (Syglas – 04/08/2008).

Figure 2.8: Syglas photovoltaic shading device example (Syglas – 04/08/2008).

- **Okasolar** systems use reflective louvers installed between insulating glass units. The louvers protected the interior from sun radiation in summer but provided diffused natural light. In winter, radiation was reflected by the louvers to the ceiling so that a large amount of sun energy and daylight could enter in the building. Okasolar units are made of clear float glass, but louvers with a concave and convex shape are made of a highly reflective, lig it ga

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reflective, light gauge steel strip with a high performance Trial coating. Louvers are fixed at a predetermined angle and spacing to respond to different seasonal conditions. Since louvers absorb a certain amount of sun radiation, increased thermal stress can occur. The outside glass pane therefore needs to be toughened or heat-strengthened, and it can have a sun control coating to reduce transmittance. The unique shape and position of the louvers permitted transmission. Reflection of light can also occur between adjacent louvers so some light is reflected to the outside and some will be transmitted into the interior. Direct light transmission varies from 3% to 58% and diffused light transmission from 13% to 28%. The louvers have a reflective surface coating so that most of the sun radiation is reflected, on the other hand absorption of sun radiation and its conversion to long wave heat radiation is minimized. The thermal insulation of Okasolar glass panels was U= 2.7 W/m^2 K (≈ 0.067 $BTU/hr.ft^2.°F$). By using a low-e coating and an argon filling in the air space, the U-value could decrease to 1.8 W/m^2 K (≈ 0.1 $BTU/hr.ft^2.°F$). In summer, all sun radiation is reflected. In transition seasons (fall and spring), radiation is partially reflected into the interior; and in winter, solar radiation is entirely reflected into the interior space. Figure 2.9 below shows Okasolar's operating system (Olbina – 2005).

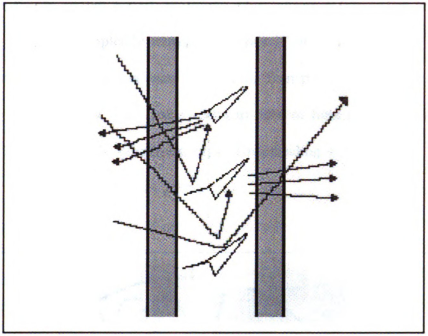

Figure 2.9: Okasolar shading device operating system (Olbina – 2005).

- **Transparent blinds**, consist of 2" wide slats made of polycarbonate. They have an L -shape with one side completely transparent and the other side frosted or translucent. The three available blind positions are:
  - *Tinted view:* the transparent side of the slats is in the vertical and closed position, providing a view and reducing glare and UV rays transmission.
  - *Open:* the slats are in the semi-open position allowing a higher percentage of direct natural light transmission and providing a view.
  - *Privacy:* the slats were tilted in the opposite direction to the tinted view position; the frosted part of the slat was in the vertical and closed position, providing privacy and obstructing a view to the outside.

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Figure 2.10 below shows a particular type of transparent blind, the Optix model, produced by Graber. Completely transparent blinds 1" or 2" wide are also available if privacy is not necessary and a view is desired. Transparent blinds can be installed horizontally and vertically. They reduce 30% to 50% of light and glare and eliminate almost 100% of the sun's ultraviolet rays. This shading device could be operated manually or automatically (Olbina – 2005).

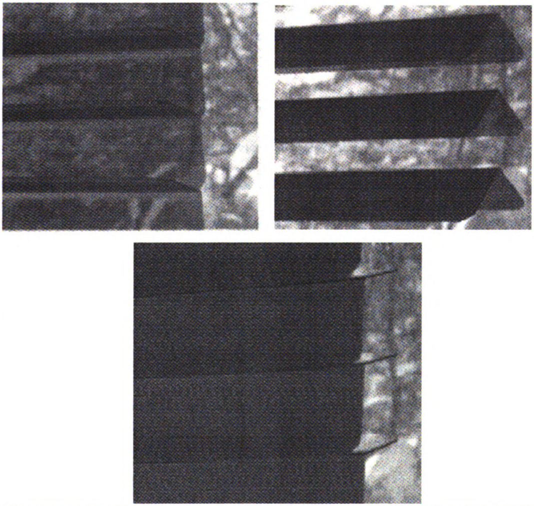

Figure 2.10: Graber transparent blind "Optix" model (Olbina – 2005).

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2.3.2.2 Patented shading device systems.

The patented shading devices made of transparent materials, such as glass or plastics, are especially interesting for application since they provide a possibility for complete transparency of windows or glass façades. The patented systems were investigated to get an understanding of their performance and the application of the principles of optical physics in the design of blinds. This is important because on important objective for designers is to improve the daylight level in the space by using shading devices. Several patented shading device systems are explained in this section and they can be divided in to moveable devices (dynamic) and fixed devices (stationary).

Moveable shading devices.

Components of moveable shading devices usually rotate around either a horizontal or vertical axis, depending on the position of the slats. Venetian blinds assemblies with rotatable horizontal slats consist of an array of rectangular symmetric prisms. These prisms are made of dielectric transparent material and are arranged on a rotatable slat. Because of refraction, the slats are not transparent, that is, the view will be distorted, but it is possible to have a view between adjacent slats. Different types of patented shading devices were studied for the scope of the research. Additional information on the use of patented movable shading devices can be found in Appendix F.

Fixed shading devices.

Fixed shading devices can be used to provide protection from direct sun rays and overheating for several hours per day. They provide protection for several months for seasonal overhea

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seasonal overheating protection, such as in the summer, or the whole year for complete solar control. The shape and position of the shading element must be carefully designed and calculated to meet these goals. The correct slat tilt angle must be chosen in accordance with the latitude and altitude angle, as well as the index of refraction of the slat material. The slope of the slat is designed to meet the requirements of total internal reflection. An example of use of fixed shading devices was given by Wirth et al. (1998) who proposed the design of a slat that consisted of concentric cylindrical shell segments because two reflections are not enough to achieve the desired efficiency of the shading device. The shading element with a cylindrical shell array provided multiple, successive, total internal reflections. The number of shell segments in the slat is limited by production capabilities. The remaining part of the slat could be left transparent or covered with a reflecting layer. This invention can be used seasonally or as an all-year solar control for orientations that provide a normal incidence angle, such as tilted, south-facing roofs or vertical east/west facing windows. Optical properties of the shading element can be changed by adding a complementary structure and by establishing optical contact between adjacent shells. A switching mechanism can be used to turn a mirror of a wide shading element into a transparent slab. One such mechanism is a thermally induced phase change of a substance from a liquid to a gas with an index of refraction approximately 1.0. This solution leads to thermally self-regulating overheating protection (Olbina – 2005).

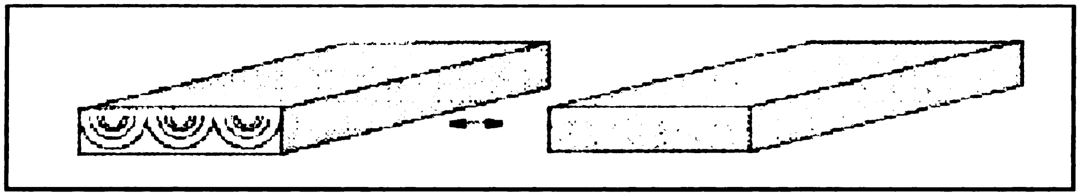

Figure 2.11: Graphic representation of cylindrical shell array and transparent slab (Olbina – 2005).

2.4 Existing research and projects.

Part of the literature review was based on existing research related to shading devices. The following were helpful in understanding the current status of research identifying gaps and what additional work still needs to be done.

"A methodology for integrated daylight and thermal analysis of buildings" – Athanassios Tzempelikos – Ph. D. Thesis 2005 – Concordia University – Montreal. Tzempelikos analyzed the issues of lighting and thermal features in buildings caused by daylight effect. During his work he defined criteria to select, evaluate and calculate the consequence of different sources, façade features and internal building conditions. Some methods he identified and used were specific and, in some cases, their applicability to general building conditions in not predictable. For instance, some of the parameters he considered were so detailed that they could not be included in a simulation program. However, some general methods that Tzempelikos used were applicable to this thesis research.

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Parameters identified by Tzempelikos influencing daylight and thermal comfort were as relevant to the research. Tzempelikos identified that a key was to determine a set of linking parameters that had an impact on both daylight and thermal performance of the space. These parameters were classified as primary and secondary, depending on their role and importance inside the user's process. The primary items were: Window Size – Window Properties – Shading Device and Properties – Shading Device Control. Electric lighting controls were considered then, as a consequence of the primary parameters selection for a given set of luminance and/or heat situations. Figure 2.12 shows the schematic organization of these concepts, as applied in Tzempelikos's research.

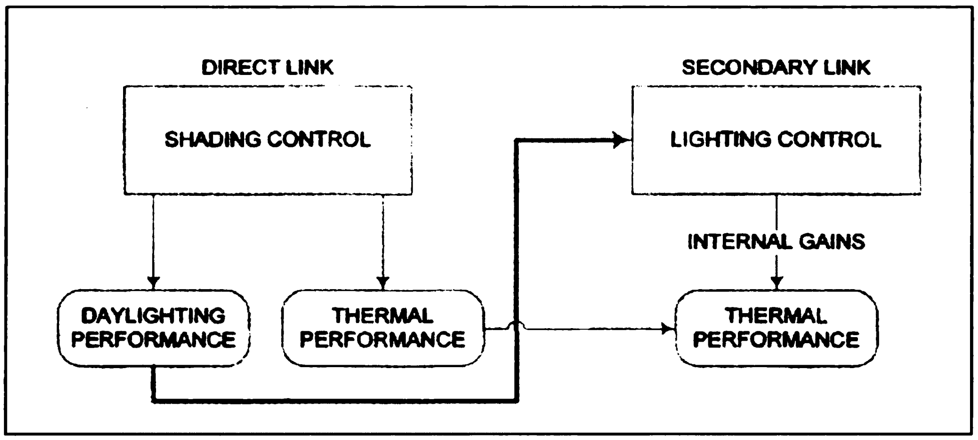

Figure 2.12: Schematic representation of primary and secondary links relations (Tzempelikos – 2005).

Another concept useful for this thesis was the distinction of the linking parameters in two categories, continuous and discreet. The first items were characterized by properties that could not be modified over time, and those that could be modified any time. An example for both of these

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Another idea that surfaced from Tzempelikos's considerations was the concept of the "three-section façade". The implementation of shading elements directly influences lighting and thermal performance, but can also have secondary effects. One of the most important as well as problematic effects is the presence of glare inside the building. As Tzempelikos reported, "recent studies have shown that for transmittance values higher than 5% - 10%, part of direct sunlight could penetrate and create glare problems for office workers" (Source: "*A methodology for integrated daylight and thermal analysis of buildings" – 2005 – pg. 91*). Therefore it was convenient to take into account a new concept of façade design, developed by Concordia University in 2003, that considered the façade to be divided in three parts (for each floor). The bottom part was opaque and should satisfy thermal insulation requirements for every considered location. The upper part was then separated in a top section, which represented the non-viewing part, and a middle section that allowed direct view to the outside and should protect the occupants from direct sunlight glares. The shading properties of the middle part should have allowed only the transmission of diffuse light into the room. On the contrary, the top part of the window, could allow beam daylight since it would not create glare problems while it maximize daylight availability.

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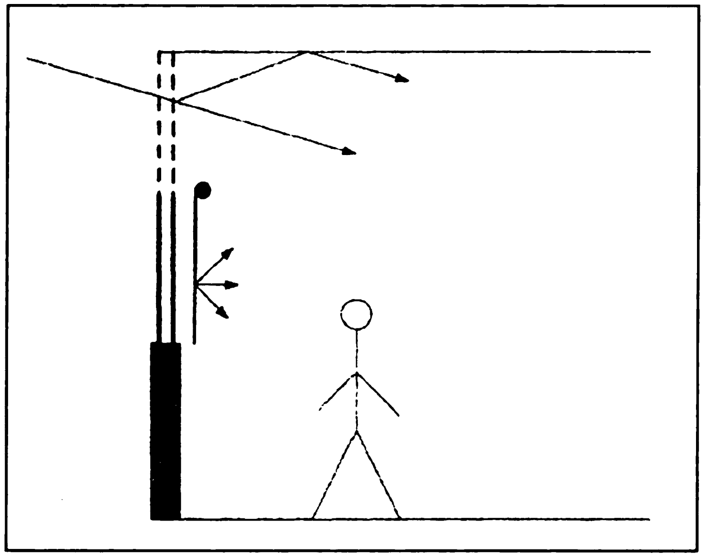

Figure 2.13: Schematic representation of the three-section façade (Tzempelikos – 2005).

This concept is graphically explained in figure 2.13 above and represents an important aspect of Tzempelikos's work. However, for this present research some modifications of the concept was necessary in considering LEED® "Indoor and Environmental Quality" chapter, EQ Credit 8.2 "90% view of spaces", requires a direct line of sight for building occupants between 2'6'' and 7'6'' for external views. An opaque surface, even if very useful for some aspects, wouldn't allow the designer to achieve that LEED® point. Therefore, researchers considered the possibility to introduce another type of façade solution, always divided in three bands but with the two upper parts fixed on a sliding system. Operable windows could have been considered not just for natural ventilation rates but also for daylight level regulations, always directly controlled by occupants. The design of a building, especially for elements that affect indoor spaces, is a process in which the project team should always leave some allowance because basic conditions such as weather, occupant perception and disposition of interior elements can not always be the same. Als

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"Decision-Making Framework for the Selection and Design of Shading Devices" – Svetlana Olbina – Ph. D. Thesis 2005 – Virginia Polytechnic Institute and State University – Virginia. After developing a general decision-making framework, this research focused on analysis of daylighting performance of shading devices and developed a specific decision-making model for selection, based on their daylight performance only. In her dissertation, Olbina first analyzed existing standards related to shading devices, windows and luminance features. Beside this topic and in relationship with it, she developed a list of all main shading devices respectively divided in existing devices, patented and a new type, developed by herself. The work was mostly qualitative in nature and reported the device features with limited technical and numeric information. Each shading device was matched with a real manufacturer and with an existing model on the market. The list included information for each device including drawings, luminance, thermal effects and applicability in LEED® projects.

As Olbina reported in the conclusion, her work left open research issues not completely developed that could constitute a core element for other research projects. One of them was the development of specific decision-making frameworks for all the of performance and building conditions not considered. The examples reported were those listed in the main framework such as thermal, acoustic, cost, control system, but there were many other aspects th

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other aspects that could have been improved, not necessarily in relationship with these ones. Between Olbina's limitations there was the issue of considering just a single-space analysis and not a whole-building environment where choices of shading devices could be influenced by other factors. The model shown below in figure 2.22 represents the first attempt of Olbina to complete a decision-making model. The research was based on four main concepts, that represent key variables in the decision-making process. These can be summarized as:

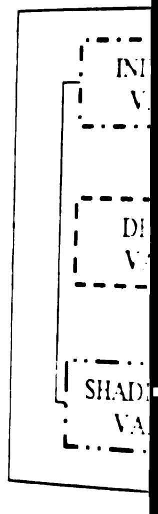
– Independent Variables (weather conditions, location, site, ...)

– Dependent Variables (heat transfer, HVAC equipment, façade type, ...)

– Shading Device Variables

– Performance Parameters (thermal, acoustic, aesthetic, ...)

As the author herself said: "the specific decision-making model developed by this research is designed as a part of a more complex decision-making model for the section/design of the shading device" (Olbina – 2005). Although the model focused only on the daylight performance of the shading device, variables used in this decision-making model can also be implemented in different situations. Olbina's research and statements were used for reference during the current research. Her identification of understanding dependent and independent shading device variables was helpful for this thesis research. Levels of energy and daylighting performance in buildings could be measured in different ways and HAP software provided different performance values. Figure 2.14 below reports the specific decision-making framework developed by Olbina.



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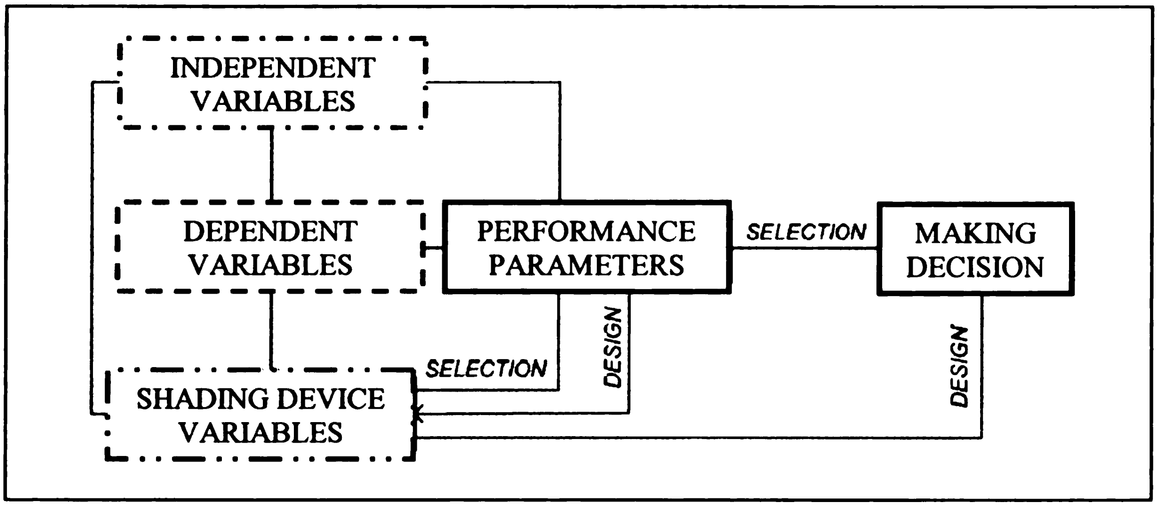

Figure 2.14: General decision-making framework.
(Olbina – 2005).

One of the points was the identification of system properties and that help determining the best solution. Different shading devices had different lighting and thermal effects on the internal environment; the use of a specific one instead of another can affect the building performance.

Within the scope of the literature review researchers also addressed the study of other existing research. However, not all findings could be implemented during the experimental sections because of software limitations. One example is the use of light pipes for whole-building analysis in order to transmit natural daylight into buildings with deep plans and increase energy savings related to electrical consumption. Additional information can be found in Appendix F.

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2.5 LEED® Background.

The research also addresses the impact of fixed shading device geometry on achievement of certain LEED® requirements. Therefore, the researcher reviewed literature on LEED® which were related to use of shading devices. The researcher was interested in identifying which solutions could be considered in order to meet LEED® Credits EA1 "Optimize Energy Performance" on a whole-building design scale. Some of the notions related to this interest are reported below and address aspects of LEED® buildings that could be implemented in order to optimize building energy performance.

The intent of LEED® EA Credit 1 ("Optimize Energy Performance") is to achieve increasing levels of energy performance above the baseline case of the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use. Three different paths could be chosen in order to comply with that requisite.

- Whole building energy simulation: that could demonstrate a percentage improvement in the proposed building performance rating compared to the baseline building performance rating per ASHRAE/IESNA Standard 90.1-2004 by a whole building project simulation. All calculations have to be based on the energy costs savings percentage (dissimilar for New Buildings and Existing Building Renovations) and depending on the achieved results, will be assigned at least 1 point, at most 10.
- Prescriptive compliance path (4 points): was developed for office buildings under 20.000 square feet and are projected to meet all applicable requisites as established in the Advanced Energy Design Guide for the climate zone in which the building is located.

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- Prescriptive compliance path (1 point): requires compliance with the basic criteria and prescriptive measures of the Advanced Building Benchmark Version 1.1 design according to the climate zone where the building is located.

Implementation of on-site renewable energy sources is also considered in EA Credit 2 ("On-Site Renewable Energy") as an applicable solution with the intent of encouraging and recognizing increasing levels of on-site renewable energy and to reduce environmental and economic impacts associated with fossil fuel energy use. The main instruction leads to an on-site use of renewable energy system to offset building energy costs. The number of points are assigned according to the percentage of the building annual energy cost supported by on-site renewable energy (from 1 to 3 points). These rates can be included in the energy modeling used in EA Credit 1 or by the Department of Energy (DOE) Commercial Buildings Energy Consumption Survey (CBECS) database (LEED NC v. 2.2).

Another feasible way to improve renewable energy supply is presented in EA Credit 6 ("Green Power") which has the intent of encouraging the development and use of grid-source, renewable energy technologies on a net zero pollution basis. That target can be reached by providing at least 35% of the building's electricity from renewable sources by engaging in at least a two-year renewable energy contract subsequent to a determination of the baseline electricity use calculated as in the EA Credit 1 or according to the Department of Energy (DOE) Commercial Buildings Energy Consumption Survey (CBECS) database.

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Other research analyzing LEED® requirements and building energy performance in buildings were previously conducted by several research teams. The Journal of Green Buildings published in fall 2007 published an article entitled "Analysis of Variation in the Energy-Related Environmental Impact of LEED® Certified Buildings" (Wedding & Brown – 2007). The related research analyzed the variability of environmental impacts due to LEED® building energy use. The whole work was based on implementation of probabilistic models that measure the energy-related environmental impact of LEED® buildings in relationship with the number of credits achieved. "Monte Carlo" methods consisting of stochastic analysis were used where each variable could be input with a certain range of values. Various models have been developed to consider several LEED® building elements, such as, building category (office, residential, ...), average intensity of energy use [EUI], percentage of electric-energy used (of the total energy consumption), KWh of based plug loads, BTU of base plug loads, energy efficiency compared with EUI of existing buildings, LEED® certification level, frequency of achievement for EA Credit 1; 2; 6.

In addition, models are based on the following assumptions.

- EUI values considered as a starting point for the analysis and calculations
- "Energy Star" values implemented as reference for the percentage of electricity used
- Other data coming from the CBECS had to be adapted to ASHRAE standards by subtracting a percentage between 2,4 and 14,8 to the average electricity consumption values
- Consideration of the "Green-e" purchase with 50 % of impact reduction instead of 100 % due to secondary effects not considered (Green-e – 03/20/2008)

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Finally the results were rendered as impact reduction values in function of the impact features, building type and certification level achieved (Wedding & Brown – 2007).

2.6 Chapter summary

This second chapter summarizes the main literature which helped to form the basis of the present research. The literature review was intended as a tool to investigate, as much as possible, existing research, articles and documentation related to shading devices. Some of the information was for the development of the research methodology. Literature review had two main scopes:

- Avoid useless repetition of existing research works
- Identify eventual gaps of knowledge on which the present research could be focused.

– CHAPTER 3 –

RESEARCH METHODOLOGY

3.1 Introductio

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3.1 Introduction.

This Section provides an overview of the methodology proposed for the research and is divided into the following subsections: 3.1 Introduction, 3.2 Shading device features, 3.3 Single-space simulation analysis, 3.4 Case-study, 3.5 Whole-building simulation, 3.6 Climate comparison, 3.7 Impact on LEED. 3.8 Development of guidelines and recommendations and 3.9 Chapter summary. Figure 3.1 below shows a graphic overview of the research methodology.

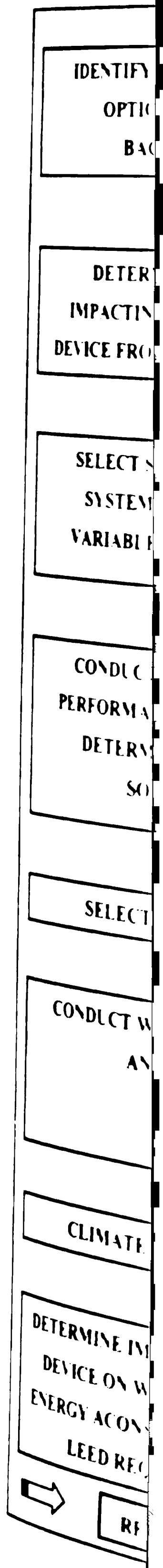

Figure 3.1

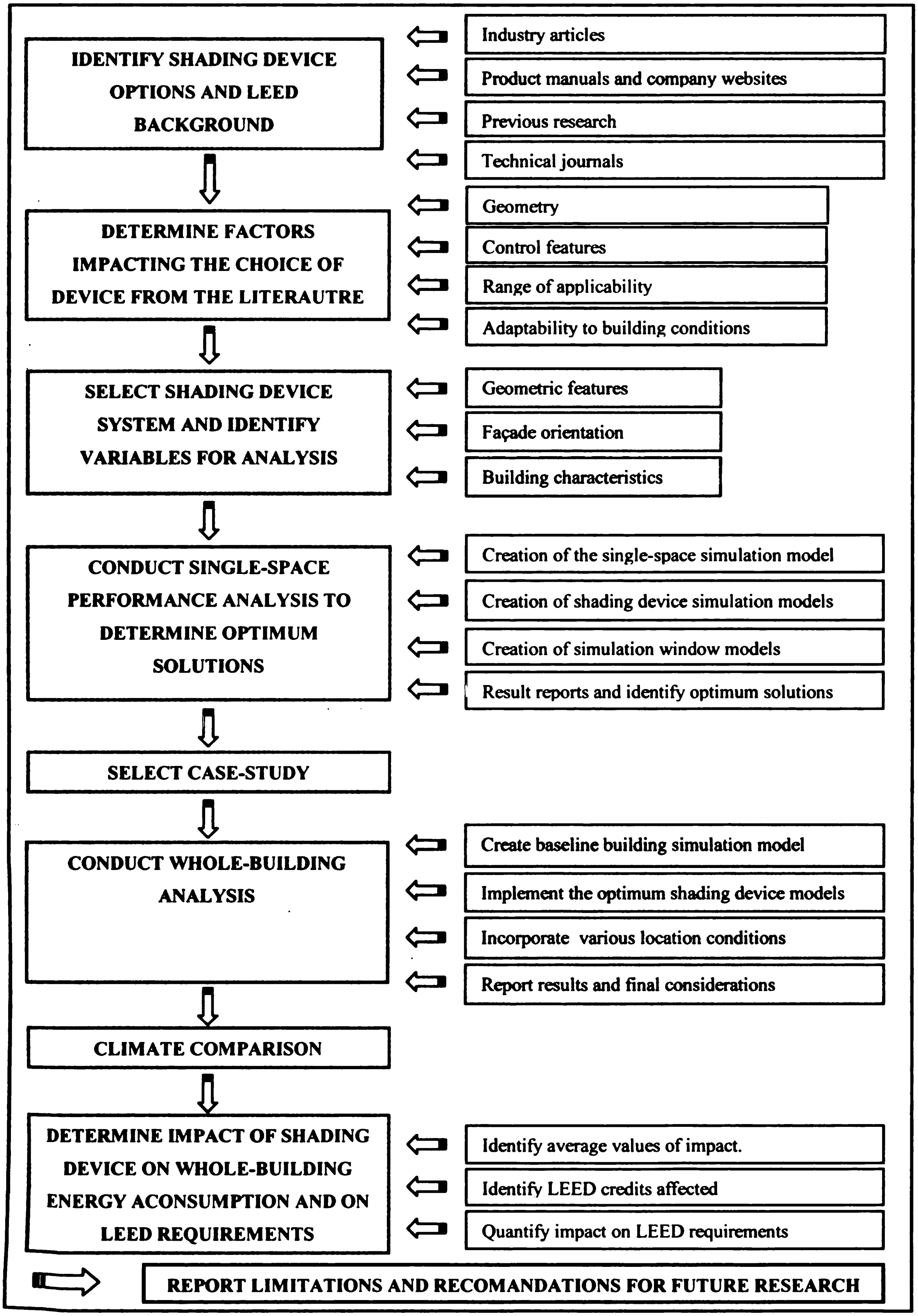

Figure 3.1: Flow model summarizing methodology and research process.

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3.2 Shading device features.

The research focused on evaluation of fixed shading devices because of their simplicity and traditional use. Specific advantages of fixed shading device were perceived by the researcher to be as follows:

- The simplicity of its geometry could allow for direct calculation of performance without depending on manufacturer's data.
- Geometry could be precisely and incrementally adjusted which allowed for a determination of their impact.
- Its ease of implementation and wide range of applicability could support its use and application to various building types.
- Being a simple and fixed device, the results of performance analysis could be adaptable to other latitudinal and climate conditions.

Analysis examined shading device geometries in order to determine their impact on energy performance. Specific features and their parameters addressed by this research are indicated below:

- Shading device geometric features (shape, inclination, dimensions).

  Dimensions (depth, width, extension beyond window lateral borders).

  Shape (dimension variation by 4 inch increment).

  Horizontal inclination.
- Device location on the building façade in respect to windows position.

  Distance from the window rim.

  Façade orientation.

Location on the façade.

3.3 Single-space simulation analysis.

This research studied the effect of fixed shading device geometry on building energy use and day-lighting using the Hourly Analysis Program (HAP E-20 II v. 4.34) developed by Carrier. This software was selected because it was one of the few software tools which met the software requirements of ASHRAE 90.1 and LEED® NC. ASHRAE 90.1 places a number of specific conditions on simulation software and they are laid out in detail in ASHRAE 90.1. Chapter 11 "Energy Cost Budget Method" and Appendix G. LEED® mandates that energy performance be evaluated in conjunction with ASHRAE 90.1 Chapter 11 and Appendix G.

The software can be used for simulation analysis, either on an hourly, monthly or annual basis. HAP E-20 II v 4.34 can be used to analyze projected energy use of single spaces or multi-space buildings. The software allows for detailed building characteristics to be incorporated, and each calendar date is related to a certain consumption level, which depends on estimated occupancy. Space models consider wall features, window area and glass characteristics. The software also incorporates building occupancy, HVAC systems, including heating, cooling and ventilation, as well as, lighting, sources of energy, occupant schedules and climate.

As cited in the literature review in section Two, virtual simulation processes have been previously used by other researchers for various types of shading devices, but not for fixed projecting

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fixed projecting elements on a whole-building-model scale, which was targeted by this current research. Prior to the whole building analysis, shading device geometries were first tested using single-space simulation in order to determine optimum solutions which were incorporated later into the whole-building analysis. The choice of a single-space model as a basis for preliminary simulations provided for quick assessment of a number of variables and allowed the researcher to narrow the range of solutions and data entry necessary with the whole building simulation. Data entry in the whole building simulation was cumbersome requiring each space to be modeled individually and assembled as part of the whole. This prior single space simulation approach reduced data entry considerably. The single-space analysis followed the steps reported below.

- *Creation of shading device simulation models:* various shading device geometries were tested on the single-space simulations to determine optimum solutions which were incorporated later into the whole-building analysis. Geometry shapes were differentiated by 4 inch increments up to a total value of 60 inch in depth, 16 inch in projection from lateral borders and 16 inch in distance from the top of the window. A total number of 375 models were created and set up, in order to determine optimum shading device geometry.
- *Creation of the single-space simulation model:* a single-space model was created on the basis of a case-study building that was also used for the whole-building analysis. HAP software required a different space for each shading device which had to be linked to a specific heating and cooling system in order to perform the analysis and so 376 single-space models were created and set up. The 376 simulations represent the sum of the 375 cases created for each shading device plus the "zero" case, for which no shading device was considered.

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- *Creation of simulation window model:* a single-window model was created on the basis of the case-study building features.

- *Result reports and identify optimum solutions:* the single-space analysis was run considering the 376 shading devices respectively linked to 376 single-spaces and 376 heat/cooling systems. Results were reported in Microsoft Excel® sheets and represented through curves and diagrams. Graphs were used to illustrate the influence of shading device geometry on energy performance as predicted by the single-space model analysis. Figure 3.2 reported below shows a plan view of the space and window configuration which was used as a basis for the single-space analysis.

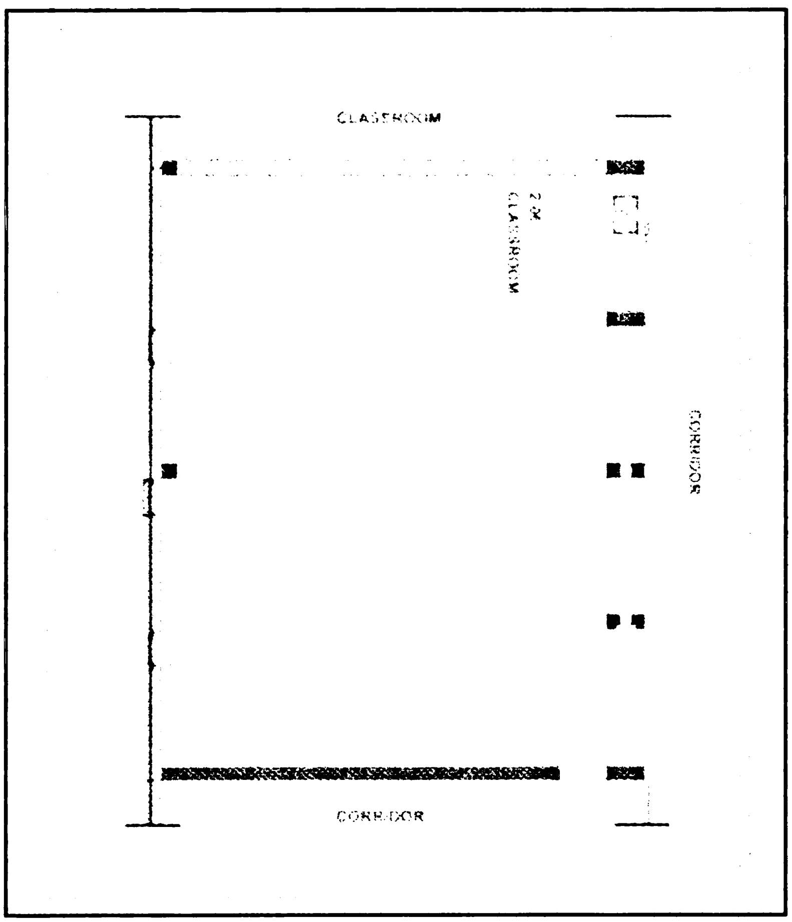

Figure 3.2: Plan view of the single-space design used for the single-space analysis.
Source: "KREG Engineering – ATA Group"

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3.4 Case-study.

A case-study approach was chosen for energy simulation modeling. Carrier HAP EII software was used for simulation and related analysis. The case-study building selected was previously modeled with HAP software without fixed shading device. This research recreated the whole-building model using the optimum fixed shading device solutions obtained from the single-space simulation. Resulting energy and daylight performance of the baseline and modified buildings were compared.

In this case the results of such shading device performance were applied to a whole building analysis to determine the impact on whole-building energy use and daylighting performance.

NOTE: an actual building was selected as the case study building in order to investigate the impact of shading devices in a real-world setting. However, the original building didn't use a complete cooling system and air-conditioning was designed only for limited portions of the building used for administrative offices. Because, many buildings are cooled and because shading devices significantly impact cooling loads, the researcher opted to extend the air conditioning systems to all spaces. This modification to the modeling of the actual building conditions was felt by the research to be more representative of most typical new buildings. Therefore, the simulation model was slightly modified from the original one by introducing an air-conditioning system serving all occupied spaces.

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3.5 Whole-building analysis.

Upon completion of the single space analyses and determination of optimum shading device geometries the researcher incorporated these optimum solutions into the whole building analyses. The structure and parameters of the whole building analysis are.

- *Create baseline building simulation model.* The virtual model was created on the basis of the case-study project and considered building design (shape, footprint area, volume and interior spaces organization), materials, occupancy rates and schedules. *Implement the optimum shading device models.* The single-space simulation showed which specific shading device geometries had the most impact and should be considered for the whole building analysis. Optimum geometries were incorporated in the whole-building model during this part of the research. The simulation placed shading devices on each window which were also be to orientation and location on the façade. The analysis showed the effect of these solutions based on the whole-building analysis. Figures 3.3 below shows the second floor plan design of the case-study building.

- *Results report and final considerations.* The results were discussed, summarized and conclusions drawn in the body of the report. Results were also reported using curve diagrams to illustrate the impact of shading device geometry and are listed below:

– Impacts of shading device geometry on single-space energy performance with identification of optimum geometries.

– Impact of shading device geometry features on whole-building energy performance, highlighting variance between the baseline and design buildings on the case-study features.

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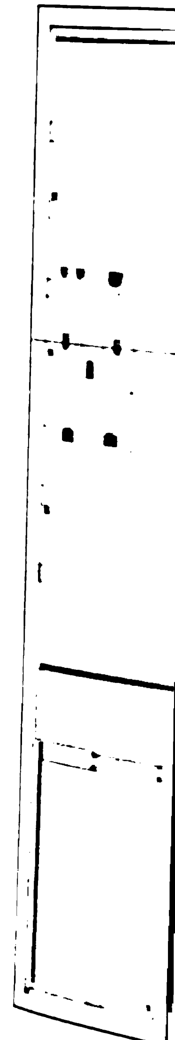

Figure

– Impact of varying latitudinal and climate zone. A limited number of analyses were proposed in order to test the validity of the results for other climates in southern Europe.

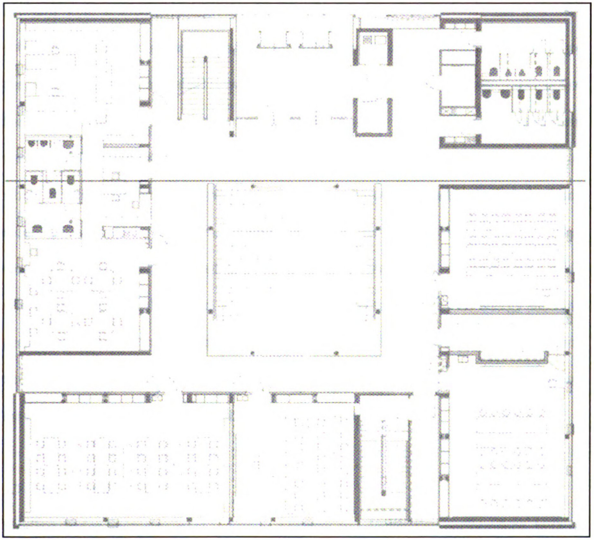

Figure 3.3: Plan view of the second floor of the case-study building.

Source: "KREG Engineering – ATA Group"

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3.6 Climate comparison.

The original case study building used as a basis for this study is located in a northern city in Italy. The researcher was interested in testing to see if the conclusions about optimum geometry were valid for other climate and latitudinal zones, therefore a limited number of analyses were conducted using other building locations. HAP software has extensive geographic specific climate data and it is relatively easy to change building location once the building has been modeled. However, given that this issue didn't represent the core of the research only a few analyses were conducted. Several locations were selected from those available in the HAP software and primarily addressed southern European cities. A whole-building simulation was run for each location, based on a standard whole-building model embodying the optimum shading device features shown in the whole-building analysis. The main objective of this subpart of the research was to explore possible effects of geographical location on how shading geometries impact on energy building performance. At the start of the research, researchers could not state if such dependency exists and, if it did, how it could affect the final results. The comparisons were used by the researcher to estimate eventual limitations of this research.

3.7 Impact on LEED®.

Shading device geometry impacts building energy and daylighting performance, both of which in turn impact the level of LEED® credits a building may achieve. LEED® represents a current practical set of industry standards and encourages whole building thinking and analysis. Therefore, the researcher was interested in considering how shading device geometry would influence the ability to achieve LEED® credits. The work was based o

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work was based on the comparison between the potential improvements obtained through the use of optimum shading device solutions and the performance required by LEED® credit EA 1. The values obtained from the analysis of the different whole-building models gave the researcher an idea of how helpful such improvements could be in pursuing LEED®. The research first tried to determine if the use of shading devices could help designers in the achievement of LEED® requirements and, if yes, which ones.

3.8 Develop guidelines and recommendations.

At the completion of the analyses, the research reported the results and conclusions. Values, diagrams and concepts were translated into guidelines which could be useful to designers and professionals who want to improve building energy performance through the use of appropriate shading devices. Guidelines were divided into several sections, which addressed a specific solution.

The first guideline reported the results of the impact of shading device geometry features on single-space energy performance. This section was followed by a short report about the choice of the best geometries to optimize the impact of shading devices on single-space energy performance.

The second guideline reported the impact of shading device geometry on whole-building energy performance, including differences between the baseline and design buildings as well as climate zone variation.

The third guideline presented considerations raised from the comparison between design-case performance improvement and achievement of LEED requirements.

3.9 Chapter summa

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3.9 Chapter summary.

This chapter presented the methods used by the researcher in order to address the objectives laid out in Section One of the proposal. Each section described the operations used to complete each part of the research, Descriptions included both the methods and the way the results are reported and illustrated.

– CHAPTER 4 –

SINGLE-SPACE ANALYSIS

4.1 Introduction

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4.1 Introduction

An important thesis objective was to study the impact of fixed shading device geometry on energy consumption on a whole-building model basis. However, as a preliminary step the researcher studied the effects of shading device geometry on a single-space model to determine optimum geometries for use in a whole-building analysis. This section reports the single space analysis approach and its results. The whole building analysis is reported in Section 5.

As indicated earlier the Arco School Project in northern Italy was used as a case study, and because of its complexity, number of spaces and functions it proved too difficult to model each of the shading device configurations directly using whole building analysis. Therefore, all calculation were developed on a smaller scale using a representative space. This allowed the researcher to enter and manage data in an efficient manor. The researcher selected a representative classroom to model the fixed shading devices along its exterior wall. Procedures and methods used for the single space analysis are reported and summarized below.

4.2 Single-Space Features.

Sample space selection.

The researcher selected a typical classroom representative of most spaces. Room 4-04 was selected. It is a regular classroom, designed for 26 students. The space is located on the second floor above an unconditioned storage space. It has a rectangular plan and is approximately 697 square fee in area. The room has one exterior wall and other three interior walls. The t

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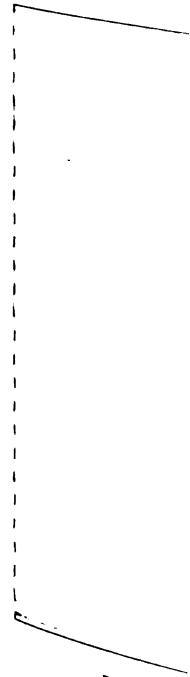

Figure

Adapted from:

interior walls. The façade is south oriented with a gross wall area of 369 square feet, a length of 28.8 ft., a height of 11.5 ft. and has window area of approximately 248 square feet. All data related to this sample-space are indicated below and, except for the orientation, are the same for all the full-time occupied classrooms of the building. Room 4-04 can be seen below in figure 4.1.

The main reasons why this classroom was chosen as reference are summarized below as follows:

- The Arco school project building is mainly formed of identical classrooms, such as this one. Other spaces (for example labs and music room) also had similar square footages and occupancy rates.
- The classrooms are regularly occupied and therefore their energy and lighting use impact whole building energy consumption heavily.

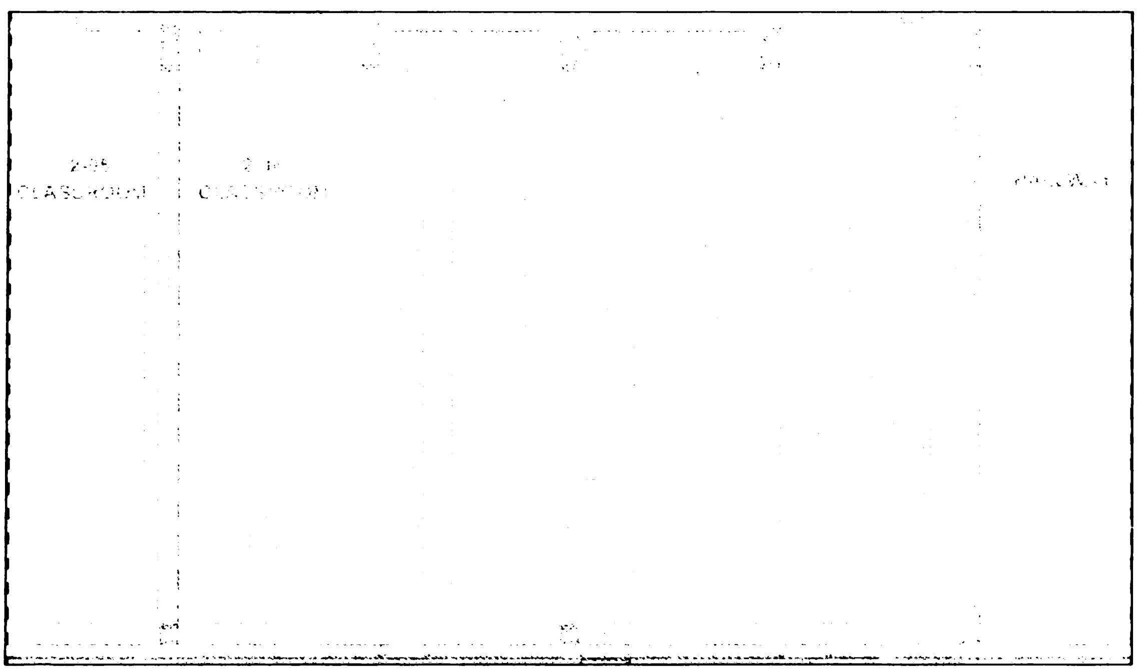

Figure 4.1: plant drawing representing the sample-space room 4-04.
Adapted from: Arco School Project – "Progetto esecutivo" – Studio AVI Associates.

Creation of the single-space virtual model

The characteristics of the representative classroom were entered into the HAP program for simulation. The HAP program doesn't support importation of drawing files, so each space parameter must be described and entered individually, which is time consuming. .However, after initial data was entered it was it is relatively easy to incorporate changes such as façade orientation and weather conditions. Listed below are the main space and construction data for the representative single space model entered into the HAP program:

General Details:

Floor Area **697.1** ft2

Avg. Ceiling Height .... **11.5** ft

Building Weight **130.0** lb/ft2

OA Ventilation Requirements:

Space Usage	**User-Defined**
OA Requirement 1	**10.6** CFM/person
OA Requirement 2	**0.00** CFM/ft2
Space Usage Defaults	**ASHRAE Std 62-2001**

Internals:

Overhead Lighting:

Fixture Type .... **Free Hanging**

Wattage **0.83**W/ft2

Ballast Multiplier **1.00**

People:

Occupancy .... **26.0** People

Activity Level .... **Office Work**

Sensible Heat .... **245.0** BTU/hr/person

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Table 4

Green Roof:

Latent Heat .... **205.0** BTU/hr/person

Façade:

Façade features		
Wall Gross Area	369	ft 2
Wall U-value	0.028	BTU/hr/ft2/F
Overall Shade Coef.	0.28	
Window and glass features		
Window U-value	0.194	BTU/hr/ft2/F
Window Height	6	ft
Window Width	5	ft

Table 4.1: external façade features required by the HAP program.

Green Roof:

Green Roof Gross Area	697.1	ft 2
Absorptivity	0.55	
LW Concrete Layer		
Thickness	6	in
Density	440	lb/ft 3
Specific Heat	0,2	BTU/lb/F
R-Value (Thermal R.)	5	hr-ft2-F/BTU
Weight	33	lb/ft 2
Bat Insulation R-25		
Thickness	8.3	in
Density	0.5	lb/ft 3
Specific Heat	0.2	BTU/lb/F
R-Value (Thermal R.)	26.6	hr-ft2-F/BTU
Weight	0.3	lb/ft 2
Built-up Roofing		

Ta

<u>Wall Details</u>:

Layers
Inside surface re
10-in High Weig Concrete
R-30 batt insulat
Air space
4-in LW concrete
Outside surface resistance
Totals

Table 4.3: ext

Thickness	0.376	in
Specific Heat	0.35	BTU/lb/F
R-Value (Thermal R.)	0.33	hr-ft2-F/BTU
Weight	2.2	lb/ft 2

Table 4.2: construction information and green-roof parameters.

Wall Details:

Outside Surface Colour .... **Dark**

Absorptivity **0.900**

Overall U-Value .... **0.028** BTU/(hr-ft2-°F)

Partition U-value .... **0.500** BTU/(hr-ft2-°F)

Layers	**Thickness** inch	**Density** lb/ft3	**Specific Ht.** BTU / (lb - °F)	**R-Value** (hr-ft3-°F)/BTU	**Weight** lb/ft3
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
10-in High Weight Concrete	10.000	140.0	0.20	0.83333	116.7
R-30 batt insulation	9.400	0.5	0.20	30.12820	0.4
Air space	0.000	0.0	0.00	0.91000	0.0
4-in LW concrete	4.000	40.0	0.20	3.33333	13.3
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	**23.400**	-		**36.22286**	**130.4**

Table 4.3: external walls construction details required by the HAP program.

Floors:

Type

Floor

Total

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4.3 Shading Dev

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Floors:

Type .... **Floor Above Unconditioned Space**

Floor Area **697.1** ft2

Total Floor U-Value .... **0.100** BTU/(hr-ft2-°F)

Unconditioned Space Max Temp. .... **75.0** °F

Ambient at Space Max Temp. .... **95.0** °F

Unconditioned Space Min Temp. .... **75.0** °F

Ambient at Space Min Temp. .... **55.0** °F

4.3 Shading Device Features.

In order to determine optimum shading device geometries, the researcher modeled a number of fixed shading devices with varying projection from the building façade, height above the window and length beyond the window edge. Data for each geometry set was entered and assigned to the single space model described above. Dimensions of each shading device were changed progressively and performance variations caused by such adjustments were calculated and collected with a sample-space analysis of the energy consumption.

After completion of all single space models, energy performance of each variation was compared to determine optimum solutions, which reduced overall annual energy consumption. Because data entry would have been overwhelming to do as many variations in the whole building analysis, the researcher selected this preliminary single space analysis approach in order to more efficiently identify optimum geometries.

Shading device

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shading device ar

- Projectior
- Height Ab
- Extension
- Reveal dep

Figu

Shading device virtual models and spaces setup.

The shading geometry parameters that were incorporated into the study for the fixed shading device are indicated below and in Figure 4.2.

- Projection From Surface
- Height Above Window
- Extension Past Right and Left-Hand Side of Window
- Reveal depth of the wall

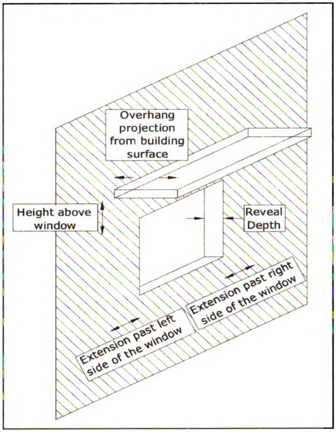

Figure 4.2: overhang shading device geometry parameters.

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The reveal depth was held constant for all simulations, however, the other three parameters were incrementally changed and their energy impact recorded and is described below.

Shading devices projection was increased incrementally from 0 to 60 inches by 4 inches increments. In all, 15 projection lengths (4, 8, 12, 16 ... in) were considered and for each of them the other two parameters of extension past the window and height above the window were set. These features were also increased in 4 inches increments up to a total length of 16 inches beyond the window and to 16 inches above the window. The whole process lead to the creation of 375 shading device virtual models (15 projection lengths * 5 lateral extensions * 5 border distances) so that every projection length could be related to a specific extension and height beyond the window borders. A big advantage of such this approach was that all input data and results could be treated as mathematical functions. At the end of the research each specific combination of input data and shading device geometry was related to a precise result in terms of energy consumption. The next step was the creation of a specific space, always equivalent to the sample-space 4-04, for each shading device geometry. The HAP simulations were based on whole-building virtual models intended as a body of spaces, systems and equipment. Therefore, each shading device and its geometry had to be related to a single space with precise characteristics. That led to the specific creation of 375 spaces, equivalents for geometry, orientation and internal characteristics but each of them provided with a different pre-modeled shading device.

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4.4 Mechanical S

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NOTE: Unfortunately the HAP program doesn't have any automation option to create a set of items with some common elements. For example, in this case each shading device had to be created manually and attached to a space. This characteristic of the program required a careful systematic approach to data entry. Moreover the potential level of failure turns out to be very high because the unassisted management of a large number of elements introduces many risks of input mistakes, not always easy to discover.

4.4 Mechanical System Settings

In order to consider a realistic virtual model a specific heating, ventilation and air conditioning system (HVAC) had to be provided for every virtual space created. HVAC systems were patterned after the Arco school project, data and utility features which fit perfectly with the scope of the research. In fact, the Arco school was originally modeled following a single-space system concept. The need to create a series of spaces with an independent system that could be individually simulated inside a virtual model retraced the same conditions of the original project. This approach allowed for direct comparison of original simulated systems with the results of the the new single-space energy performances, providing for evaluation of the energy improvements caused by the shading device geometry variations. HVAC equipment consisted of a common ventilation system with terminal units connected to several packaged DX fan coils and return air ducts.

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Additional data ab

provided below.

All systems and spaces previously defined in respect of the 4-04 Room characteristics and dimensions had to be organized by mechanical system groups before creating the final model. Such groups would have been used during the next step for the creation of a fictitious plant that would have formed the first building simulation. The HAP program also requires the single space and system set-up information about their location, grouping characteristics and systems, be input. In order to achieve this point the model had to include individual systems with identical features for every previously-created single space. That implied the progressive set-up of 375 different systems, each of them addressed to a single space equivalent to the room 2-06 but characterized by different shading device geometries.

The HAP program allows analysis either at a system, building or plant level. Loads and energy input can be calculated in relationship to all systems such as HVAC and lighting. Setting up one single building and one plant model for each system was not necessary for the single-space model analysis. Unfortunately, the HAP program can support only up to 200 systems per file, so the 375 single-room systems had to be split into two different files and the analyses run separately. The results were later collected in a single spreadsheet which allowed the researchers to evaluate all configurations together.

Additional data about the ventilation equipment assigned to each single-space system are provided below.

Ventilation Syst

Ventilation Ai

Ventilation Re

Ventilation Fan

% Airflow	10
% kW	10

Table 4.4: prop

Thermostats and

NOTE: cooling syst

Ventilation System Components:

Ventilation Air Data:

Airflow Control .... **Constant Ventilation**

Airflow..

Ventilation Sizing Method .... **Sum of Space Airflows**

Unocc. Damper Position .... **Closed**

Damper Leak Rate .... **0** %

Outdoor Air CO2 Level .... **400** ppm

Ventilation Reclaim Data:

Reclaim Type .... **Sensible Heat**

Thermal Efficiency .... **95** %

Schedule .... **January - December**

Ventilation Fan Data:

Fan Type .... **Forward Curved**

Configuration .... **Draw-thru**

Overall Efficiency .... **54** %

% Airflow	100	90	80	70	60	50	40	30	20	0
% kW	100	91	81	72	61	54	46	40	33	21

Table 4.4: proportion ratios between airflow rates and the energy use percentages.

Thermostats and Zone Data:

Cooling T-stat: Occ. .... **75.0** F°

Cooling T-stat: Unocc. .... **85.0** F°

Heating T-stat: Occ. .... **70.0** **F°**

Heating T-stat: Unocc. .... **60.0** **F°**

T-stat Throttling Range .... **3.00** **F°**

NOTE: cooling system was considered enable also for unoccupied spaces.

Common Termina

Cooling Coil:

Heating Coil:

Terminal Units D

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Sizing Data (Comput

System Sizing

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Hydronic Sizin

Chill

Hot W

Safety Factors:

Cooli

Cooli

Heatin

Common Terminal Unit Data:

Cooling Coil:

Design Supply Temperature .... **58.0** °F

Coil Bypass Factor **0.100**

Cooling Source .... **Air-Cooled DX**

Schedule .... **January - December**

Heating Coil:

Design Supply Temperature .... **110.0** °F

Heating Source .... **Hot Water**

Schedule .... **January - December**

Terminal Units Data:

Zone .... **All**

Terminal Type .... **Fan Coil**

Minimum Airflow .... **0.00** CFM/person

Fan Performance .... **0.6** kW

Sizing Data (Computer-Generated):

System Sizing Data:

Cooling Supply Temperature .... **58.0** °F

Heating Supply Temperature .... **110.0** °F

Hydronic Sizing Specifications:

Chilled Water Delta-T .... **10.0** °F

Hot Water Delta-T .... **20.0** °F

Safety Factors:

Cooling Sensible .... **0** %

Cooling Latent .... **0** %

Heating **0**..%

Zone Sizi

Supply Airflo (CFM)
501.7

Equipment Data

Estimate Maximur Load (MBH)
18.6

Table 4.

4.5 Window Feat

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Zone Sizing Data:

Zone Airflow Sizing Method .... **Sum of space airflow rates** ....

Space Airflow Sizing Method .... **Individual peak space loads**

Supply Airflow (CFM)	Zone Htg Unit (MBH)	Reheat Coil (MBH)	Ventilation (CFM)
501.7	-	-	275.6

Table 4.5: zone sizing data parameters.

Equipment Data

Estimated Maximum Load (MBH)	Design OAT (°F)	Gross Cooling Capacity (MBH)	Compressor & OD Fan Power (kW)	Cutoff OAT (°F)
18.6	**95.0**	**23.9**	**2.43**	**55.0**

Table 4.6: list of parameters set up for each single-space equipment.

4.5 Window Features Settings and Optimum Solution Selection.

The researcher originally modeled the window proportions as it was in the original building. The original plans of the selected room called for continuous band windows on the south façade. The specified window dimensions were 31 feet in length and 7.89 feet in height. After preliminary study it was easy to determine that projection beyond the window length would have relatively little proportional impact.

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Additionally, the overall height of the window and overall area would tend to mitigate the impact on any shading devices. Consequently, the researchers identified the following concerns about the original windows:

- Shading device projection from the edges ranged between 4 and 12 inches, were very small relative to the 31-feet length of the continuous-band windows.
- The height of the original window could have been excessive in order to have tangible values of shading device impact on single-space energy performance.
- The area of the window, as shown in the original project, would cover more than the half of the whole façade surface. 244 square feet (31 x 7.89 sq. ft.) out of the total 467 façade square feet were designed as glass surface. Therefore, the average thermal inertia of the single-space would have been much lower than the ones of any other internal or semi-internal spaces of the building.

In order to clear these issues researchers had to make sure that single-space analysis were not affected by such exceptional window areas which could distort or hide the shading device impact on energy consumption. Therefore, four different analyses with different window areas were developed and analyses run. All analyses were based on the same single-space, façade and shading device features. For the four analyses all 375 shading devices were considered and U-values for glass and walls were not modified. Researchers chose the single 5 ft. x 6ft. window as the basic modular unit for exterior openings because it reflects an average window size for this type of buildings. At the same time, the regularity of its dimensions allows for multiple windows and separation between windows along the single-space façade. The Analyses are classified as follows:

- ANALYSIS A: one window of 5 by 6 feet.

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variation was taken

- ANALYSIS B: one window of 10 by 6 feet.
- ANALYSIS C: five windows of 5 by 6 feet.
- ANALYSIS D: one window of 31 by 7.89 feet (original design).

<u>**NOTE:**</u> HAP software considers windows as "holes in the exterior walls", not as "additional glass area". In other words, operators always have to input all data of various walls, as if each space didn't have any exterior opening. Each wall is characterized by an orientation, an average U-value and other features. Then, windows are assigned to each wall and by doing that, the program subtracts the window areas from the original wall areas previously input. Therefore, for this set of analyses, the parameters the researchers had to change were the height, width and number of windows on the façade. No other parameter of the single-space model was modified.

At the end of each analysis every combination of shading device variables corresponded to a specific value indicating the annual energy consumption of the single-space model. The annual energy consumption value ("total load" value) was calculated as the sum of three different factors, Central Cooling Coil Load, Central Cooling Equipment Load and Central Heating Coil Load respectively related to cooling and heating loads. After a sorting process done through a specifically designed spread sheet, all shading device geometry combinations were ranked on the basis of the annual energy consumption values, as shown in tables 4.6 and 4.8 below. Optimum solutions were identified on the basis of minimum gaps between total energy load results. The tolerance for total load variation was taken as 0.1%.

Depth, length, edge ext. (inch.)	Ce
4,0,00	
4,4,8-8	
4,16,16-16	
16,0,00	
16,4,8-8	
16,16,16-16	

Table 4.

Depth, length, edge ext. (inch.)	Ce
4,16,16-16	
4,4,8-8	
4,0,00	
16,16,16-16	
16,4,8-8	
16,0,00	

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Depth, length, edge ext. (inch.)	Central Cooling Coil Load (kBTU)	Central Cooling Eqpt Load (kBTU)	Central Unit Clg Input (kWh)	Central Heating Coil Load (kBTU)	Central Heating Coil Input (kWh)	TOTAL LOAD (kBTU)
4,0,00	1729	1729	122	15787	4501	19244
4,4,8-8	1752	1752	122	15787	4512	19291
4,16,16-16	1755	1755	122	15787	4506	19296
16,0,00	1632	1632	121	15744	4509	19007
16,4,8-8	1658	1658	121	15744	4517	19060
16,16,16-16	1726	1726	121	15744	4513	19196
...	...	...	...	...	...	...

Table 4.7: snapshot of the analysis result list before the sorting process.

Depth, length, edge ext. (inch.)	Central Cooling Coil Load (kBTU)	Central Cooling Eqpt Load (kBTU)	Central Unit Clg Input (kWh)	Central Heating Coil Load (kBTU)	Central Heating Coil Input (kWh)	TOTAL LOAD (kBTU)
4,16,16-16	1755	1755	122	15787	4506	19296
4,4,8-8	1752	1752	122	15787	4512	19291
4,0,00	1729	1729	122	15787	4501	19244
16,16,16-16	1726	1726	121	15744	4513	19196
16,4,8-8	1658	1658	121	15744	4517	19060
16,0,00	1632	1632	121	15744	4509	19007
...	...	...	...	...	...	...

Table 4.8: snapshot of the analysis result list after the sorting process.

Each analysis led to the identification of an optimum solution, intended as the combination of shading device variables that implies the lower amount of annual energy consumption. At the end of the process, total load values from the analyses A, B, C and D were different, even for the same combination of geometrical variables. However, the list of total load values, each of them associated with a specific variable combination, had the same ranking order for both cases C and D. This was one of the main reasons that made the researcher choose the optimum solution identified by analysis C and D. Other causes and elements that lead to such conclusions are explained below in the discussion of the conclusions for each window-type analysis.

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  extension, i

For each analysis 376 combinations of shading device geometries were considered, the original 375 resulted from the three variable increment in addition to the case "0", for which no shading device was considered. 1504 values were determined for the four cases. Besides analyzing the four optimum combinations of variables resulting from the four different analyses, researchers also drew some general conclusion related to groups of values, in order to reach a general understanding of the results. The key element that led the data sorting process was depth from wall which proved to be the most impacting variable on single-space energy consumption. The main conclusions about optimum solutions that the researchers drew for each run of the single-space analysis are reported below.

ANALYSIS A – one single "5 by 6 feet" window.

In this case, all resulting values related to the annual total energy load varied by a range of 1%. In all cases the impact of shading devices could be considered irrelevant because gaps between different load values were smaller than 0.1%. Researchers determined several factors led to the smaller than expected improvement which are identified below.

- The optimum combination of variable turned out to be the "36 inch depth, 0 inch height above window, 0-0 inch projection from the edges" (36 depth,0 height,0-0 extensions), with a total load of 18325 kBTU.
- The worst combination of variable, which was the 8 depth,0 height,12-12 extension, indicated a total annual load of 18528 kBTU.

- This 203 kBTU range between best and worst combination represented approximately the 1% increment of the total load value, contained all results of the 376 combinations of variables.
- The sorting process done through the annual load values ranking operations apparently didn't show any rational connection between variable increments and total load variation. Long and short projections, wide and narrow edges, big and small distances from the border appeared in a sequence didn't reflect any correlation between variables and total energy load values.

Shading device depth (inch.)	Height above window range (inch.)	Extension from sides (range) (inch.)	Space energy load (range) (kBTU)
0	\	\	18326
4	0 - 16	0 - 12	18388 - 18337
8	0 - 16	0 - 12	18528 - 18341
12	0 - 16	0 - 12	18508 - 18353
16	0 - 16	0 - 12	18459 - 18341
20	0 - 16	0 - 12	18484 - 18337
24	0 - 16	0 - 12	18419 - 18335
28	0 - 16	0 - 12	18393 - 18439
32	0 - 16	0 - 12	18347 - 18432
36	0 - 16	0 - 12	18325 - 18416
40	0 - 16	0 - 12	18382 - 18433
44	0 - 16	0 - 12	18327 - 18427
48	0 - 16	0 - 12	18369 - 18497
52	0 - 16	0 - 12	18387 - 18469
56	0 - 16	0 - 12	18386 - 18501
60	0 - 16	0 - 12	18399 - 18518

Table 4.9: summary table showing ranges of result values for analysis A, related to the 5-by-6 single window configuration.

The main causes of this inconclusive set of results were related to the smallness of the window area and can be summarized as follows:

- Low solar impact on heating and cooling loads caused by the small glass area.
- High average U-value for exterior and interior partitions, made mostly of solid wall and little glass.
- High value of thermal capacity. Exterior walls, as well as the entire building partitions, were classified in HAP software as "heavy structure". This input has direct consequences on the thermal mass of the space. In other words, it affects the capability of the structure of retaining heat (or cold, depending on the outside temperature) when no air conditioning equipment is running. This factor homogenizes the temperature throughout the whole day and night time reducing energy needs and solar impact on heat gains. Other aspects of thermal capacity effects in buildings are explained more specifically at the end of chapter 4.

ANALYSIS B one window of 10 by 6 feet:

This case partially reflects the results obtained for the previous analysis:

- The optimum combination of variable was identified as the "32 inch depth 16 inch height above window, 0-0 inches projection from the edges" (32,16,0-0), with a total load of 18,536 kBTU.
- The worst combination of variable, corresponding to the 56 depth,4 height,4-4 extension, indicated a total annual load of 18,943 kBTU.

Once again the range of values showed a total increment of 407 kBTU for all the 376 analyzed combinations. The causes are the same as the ones listed above for analysis A and therefore researchers decided not to consider these values for the scope of the research. However, in this case at the end of the ranking operations the list of values appeared more organized than the one obtained for analysis A. The sorting process lined out some criteria, based on the depth, that characterized the whole set of values and are summarized below:

- Shading devices with projection length between 20 and 40 inches, regardless of the other two variables, were the best-ranked solutions.
- Shading devices with projection length below the 20 inches occupied the average band of values.
- Shading devices with projection length above the 40 inches constituted the bottom of the pool in terms of energy performance values.

Shading device depth (range)	Height above window range	Extension from sides (range)	Space energy load (range)
(inch.)	(inch.)	(inch.)	(kBTU)
0	\	\	19025
4	0 - 16	0 - 12	18732 - 18761
8	0 - 16	0 - 12	18697 - 18750
12	0 - 16	0 - 12	18656 - 18700
16	0 - 16	0 - 12	18634 - 18700
20	0 - 16	0 - 12	18559 - 18590
24	0 - 16	0 - 12	18563 - 18665
28	0 - 16	0 - 12	18588 - 18731
32	0 - 16	0 - 12	18544 - 18677
36	0 - 16	0 - 12	18567 - 18817
40	0 - 16	0 - 12	18664 - 18849
44	0 - 16	0 - 12	18600 - 18864
48	0 - 16	0 - 12	18787 - 18914
52	0 - 16	0 - 12	18659 - 18904
56	0 - 16	0 - 12	18659 - 18855
60	0 - 16	0 - 12	18754 - 18885

Table 4.10: summary table showing ranges of result values for analysis B, related to the 10-by-6 window configuration.

The differentiation between categories was gradual and the intent of this brief description is to give a sense of how total load vales were ranked throughout the result list. Complete lists of values are reported in appendix C.

<u>ANALYSIS C (five 5 ft. x 6 ft. windows) and ANALYSIS D (one 7 ft. x 31ft. window):</u>

These cases reflected the results that researchers expected. Both sets of results had the same optimum combination of variable, as well as, the whole ranking order based on annual energy consumption and the listing sequence didn't present any random element such as with analyses A and B. Projection length appeared to be, once again, the most important variable governing the ranking list of energy consumption values. The main data collected from the two analyses is summarized here below:

- The optimum solution appeared to be the "56 depth, 12 height, 4-4 extension" with an annual energy consumption of 20019 kBTU for analysis C and 21520 kBTU for analysis D.
- The worst combination was identified as the "4 depth, 12 height, 0-0 extension", with an annual energy consumption of 20511 kBTU for analysis C and 23584 kBTU for analysis D.

Especially for analysis D, shading device impact is clearly identifiable because the range of values obtained constitutes 9.5% of total annual energy consumption. The results based on the projection length suggested the following:

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- Projection lengths between 40 and 60 inches induced the best energy consumption values.
- Projection lengths between 20 and 40 inches induced average energy consumption values.
- Projection lengths between 4 and 20 inches induced low energy consumption values.

Shading device depth (range)	Height above window range	Extension from sides (range)	Space energy load (range)
(inch.)	(inch.)	(inch.)	(kBTU)
0	\	\	21784
4	0 - 16	0 - 12	20478 - 20511
8	0 - 16	0 - 12	20451 - 20511
12	0 - 16	0 - 12	20376 - 20481
16	0 - 16	0 - 12	20330 - 20396
20	0 - 16	0 - 12	20234 - 20353
24	0 - 16	0 - 12	20217 - 20327
28	0 - 16	0 - 12	20198 - 20286
32	0 - 16	0 - 12	20304 - 20138
36	0 - 16	0 - 12	20079 - 20241
40	0 - 16	0 - 12	20051 - 20241
44	0 - 16	0 - 12	20082 - 20214
48	0 - 16	0 - 12	20102 - 20243
52	0 - 16	0 - 12	20118 - 20353
56	0 - 16	0 - 12	20019 - 20357
60	0 - 16	0 - 12	20070 - 20355

Table 4.11: summary table showing ranges of result values for analysis C, related to the five 5-by-6 windows configuration.

NOTE: In each analysis the worst energy performance was given by the "0" case, which had a 0 inch depth, 0 inch height and 0 inch edges shading device, equivalent to not using any shading device.

Shading device depth (range)	Height above window range	Extension from sides (range)	Space energy load (range)
(inch.)	(inch.)	(inch.)	(kBTU)
0	\	\	24943
4	0 - 16	0 - 12	23437 - 23583
8	0 - 16	0 - 12	23294 - 23429
12	0 - 16	0 - 12	23043 - 23279
16	0 - 16	0 - 12	22916 - 23187
20	0 - 16	0 - 12	22371 - 22992
24	0 - 16	0 - 12	22034 - 22904
28	0 - 16	0 - 12	22173 - 22748
32	0 - 16	0 - 12	21827 - 22797
36	0 - 16	0 - 12	21832 - 22727
40	0 - 16	0 - 12	20051 - 20241
44	0 - 16	0 - 12	20082 - 20214
48	0 - 16	0 - 12	20102 - 20243
52	0 - 16	0 - 12	20118 - 20353
56	0 - 16	0 - 12	20019 - 20357
60	0 - 16	0 - 12	20070 - 20355

Table 4.12: summary table showing ranges of result values for analysis D, related to the 31-by-6 window configuration.

Single-space analysis results are graphically summarized in figures 4.3 and 4.4 below. In figure 4.3 values indicating single-space annual energy consumption are shown as a function of the fixed shading device projection length. Figure 4.4 shows the energy consumption improvement caused by shading device implementation as a function of the projection length.

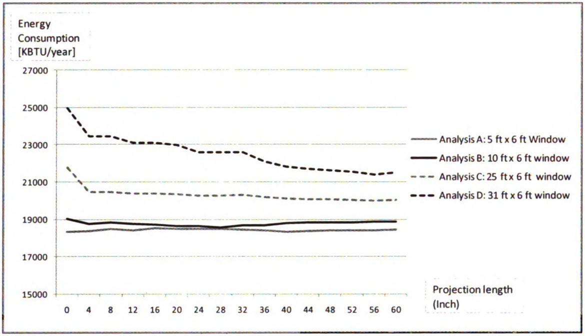

Figure 4.3: graphical representation of analysis A, B, C and D results.

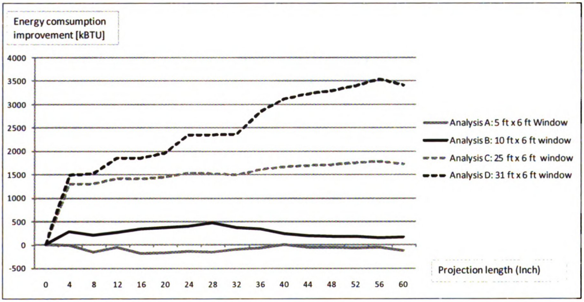

Figure 4.4: graphical representation of energy consumption improvement values obtained from analysis A, B, C and D.

In order to display the impact of secondary variables (height and lateral extension) on total energy consumption researchers focused on the range of values obtained for a specific projection length. The projection length chosen for this type of investigation was the optimum one. Results related to energy consumption for the 56 inches projecting shading device are reported below. Figure 4.5 shows that the closer the shading device is to the top of the window and the farther the extension, less energy will be used In the building. However, these effects are very small in relation to the impact of projection on energy use.

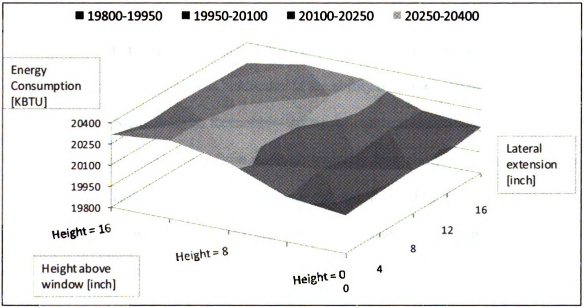

Figure 4.5: graphical representation of energy consumption range for 56-inches-projection shading devices.

4.6 Single-Space Result Validation.

The unpredictability of values obtained for analysis A and B raised some concerns about the accuracy of results. Two main issues were highlighted. First of all the sequence of values proceeded from the sorting process based on total annual energy load didn't show any apparent correlation with shading device variables. Moreover, the gap between best and worst energy performance was almost undetectable. Upon advice of mechanical engineer, the researchers focused their attention on the possible side effect of high thermal mass values related to concrete walls. The whole school building was simulated in HAP program as a "heavy structure", with an average density value of 130 pounds per square foot, typical of concrete structure buildings in Italy. This specific characteristic is the main factor that influences thermal mass effects causing discrepancies in energy load balance.

The concept of thermal mass is strictly bound to the concept of thermal capacity, which is defined by Stein and Reynolds as "indicator of the ability of a fixed volume of material to store heat" (Ben Stein, John S. Reynolds – 2006). In reality this definition is not precise but it gives an intuitive idea of the main concept. In fact, the principles that govern thermodynamic laws are based on temperature and thermal gradients, not on heat quantities. More specifically the thermal capacity is related to the speed at which a certain body characterized by a specific temperature reaches the thermal equilibrium with the environment it's dipped in under specific convection, conduction and irradiation conditions (Kalema T. et al. – 2008).

A study about thermal capacity and mass effects on residential construction systems was recently developed by Katerine Gregory and other Australian researchers. The work focused on a single-space model and analyzed the impact of varying thermal mass features on energy performance, by simulating four different construction systems. Analysis results showed that "thermal mass has the ability to significantly reduce energy usage in residential buildings by maintaining a comfortable internal temperature" (Gregory et al. – 2007). However, in order to have result consistency between different single-space simulations, increasing window area requires thermal mass to be increased proportionally (Gregory et al. – 2007). According to Gregory, thermal mass strongly impacts building energy performance especially in systems like the Arco school, in which the schedule of use and the exterior temperature varies completely from night to day periods. The whole concept could be briefly explained as follows. If the whole heating and cooling systems are shut down during part of the day the internal environment temperature tends to reach the equilibrium with the external one. However, if the time needed by the internal environment to reach such equilibrium is longer than the period in which systems are shut down due to the presence of big thermal mass, then the quantity of energy needed to bring internal spaces to the previous temperature would be lower than the one of a low-thermal mass building.

With respect to the present research, results of Gregory's study were considered as guidelines for the choice of the optimum shading device solution. Researchers decided to choose, for the single-space simulation, a window configuration for which the proportion between gross wall and glass area of the single-space could match with that of the whole-building. Bearing in mind that all exterior walls of the structure had the same U-value and thermal capacity, the total exterior wall area of the building was divided by the total window area. The ratio between overall wall and window area of the building turned out to be approximately 2.55. While considering the single-space simulation the total gross area of the exterior wall was 369 square feet. Researchers applied the same proportion to the single-space model finding a fictitious window area of 145 square feet. Such area value resulted very close to the one given by the five-by-six-feet windows case, in which 5 punctured windows were considered with a total glass area of 150 square feet and a ratio between single-space wall and window area of 2.45. This particular consideration led researchers to the choice of the 5-by-6-feet window simulation as the case to select the shading device optimum solution which would be modeled in the whole building simulation addressed in Chapter 5. The optimum solution coincided with the following shading device variables combination: 56 inches projection, 12 inches height above window and 4 inches projection from both sides.

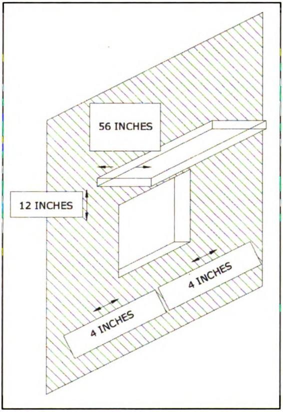

Figure 4.6: overhang shading device geometry parameters for the optimum solution.

4.7 Chapter Summary.

This chapter describes the process followed by researchers to define the single-space features for the single-space analysis. Reasons for supporting researcher's choices are reported and explained. Variables used to consider different shading devices and window configurations on the single-space analysis are explained, as well as, reasons and processes that led researchers to their choice. Finally the combination of shading device variables and window configuration which were selected as the "optimum solution" in terms of single-space energy performance is identified.

– CHAPTER 5 –

WHOLE-BUILDING ANALYSIS

5.1 Introduction.

The single-space analysis discussed in chapter 4 was used to establish the optimum shading device solution for use in a whole building analysis. The optimum solution was one which yielded the lowest energy consumption from all the analyses and dimensions of 56 inch projection from the wall, 12 inch height above window and 4 inches projection from the lateral edges.

After studying the single space analyses the researcher used the optimum solution to study its impact in a whole building solution, again using the Arco School case study as a basis for analysis. The whole building simulation named "whole-building optimum solution" (WBOS) considered one optimum shading device installed over each of the school windows. Annual energy consumption values resulting from the WBOS analysis (design case) were compared to the original building annual energy consumption values and design configuration (baseline case). The difference between baseline and design cases energy consumption gave the potential energy savings for the whole building on an annual basis.

In order to test the results for varying climate conditions, the same process of comparison between design and baseline case was repeated for four geographical locations of the building related to an equal number of weather conditions, sun exposures, longitude and latitude values. All locations were chosen in the South Europe area and within the HAP software restrictions, which provides a limited number of pre-set conditions. The decision to test the difference of annual energy performance between baseline and design cases was taken in order to help normalize the research results. The researchers opined that the shading device solutions and energy savings could be strictly related and dependent on geographical location of the building. If so, the present research would be valid just for the northern Italian area, otherwise its results could be applied to a broader area. Details related to the choice of the different locations for the whole building simulation analysis are explained in at the end of chapter 5.

5.2 Whole-Building Features Overview.

The project chosen as a reference for conducting the whole building energy simulation is a middle school complex. The core is formed by the classroom building where all office and main educational activities are performed. This portion of the building is characterized by a total area of about 28,500 square feet. The whole structure is on three main floors plus an unconditioned basement level that matches with the whole classroom building footprint. Additionally, the school complex also includes a 9,667 square feet gymnasium with opposite locker room and related facilities as well as cafeteria, kitchen and service area. A detailed list of all school spaces and their areas is reported in figure 5.1 below.

In order to develop the energy simulation the HAP software requires the input of different types of data. For the modeling in the software each building is characterized by various systems intended as the whole group of mechanical devices that provide and perform any kind of mechanical-related function in the building (heating, cooling, air fan, ...). Each system is designed to serve a limited number of spaces, each of them characterized by specific design features, as already shown in Chapter Four for the single space analysis. Each group of spaces linked to one single mechanical system was defined as a "thermal

The Arco school project was designed to have a central heating plant that could supply heat to every space of the building. Therefore all data related to the central heating plan were also input in the HAP software.

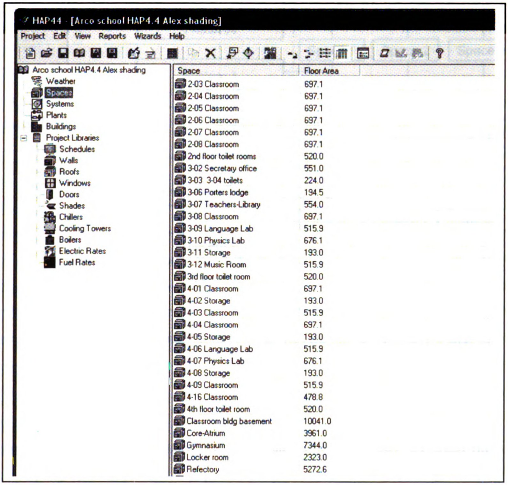

Figure 5.1: snapshot of HAP E20-II program showing all spaces considered for the whole-building analysis with the related square feet floor areas.

At a whole-building simulation level, researchers had to input two types of data, the first related to the building design, intended as the sum of all single space design features, and the second ones related to the mechanical system design. Figure 5.2 below shows a simplified scheme related to the types of data that were input in the HAP energy model.

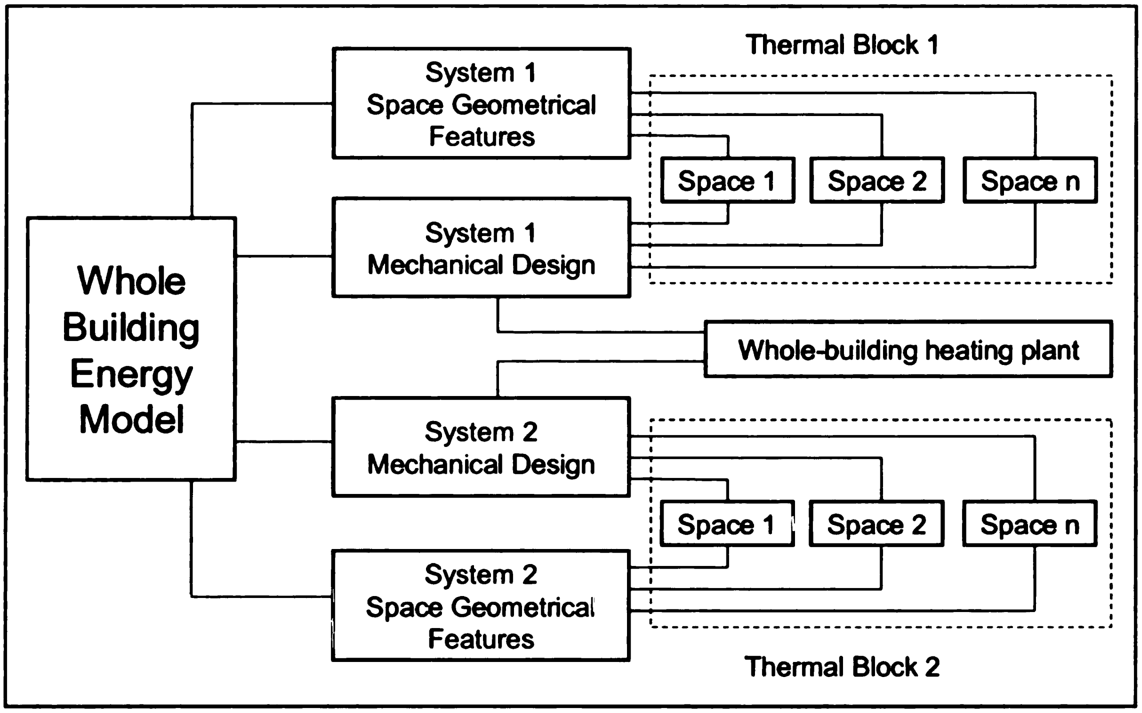

Figure 5.2: schematic representation of HAP operating mode for whole-building energy simulation.

A summary of all features related to each space that were used to setup the whole-building simulation are reported in table 5.1 below. Further and more detailed information are reported in appendix D.

- **General Details:**
  Floor Area
  Avg. Ceiling Height
  Building Weight

- **OA Ventilation Requirements:**
  Space Usage
  OA Requirement 1
  Space Usage Defaults

- **Overhead Lighting:**
  Fixture Type
  Wattage
  Ballast Multiplier
  Lighting Schedule
- **Task Lighting:**
  Wattage
  Schedule
- **Electrical Equipment:**
  Wattage
  Schedule
- **People:**
  Occupancy
  Activity Level
  Sensible Heat
  Latent Heat
  Occupancy Schedule
- **Walls, Windows, Doors:**
  Wall Type
  WindowType
  Window Shade Type
  Door Type
- **Roofs, Skylights Features:**
  Exposion
  Roof Gross Area
  Roof Slope
  Skylight Quantity
- **Infiltration:**
  Design Cooling
  Design Heating
  Energy Analysis
- **Floors:**
  Type
  Floor Area
  Total Floor U-Value
  Unconditioned Space Max Temp.
  Ambient at Space Max Temp.
  Unconditioned Space Min Temp.
  Ambient at Space Min Temp.
- **Internal Partition Details.**

All processes and activities related to the simulation set up were performed on the basis of an existing project previously developed by Italian companies and offices. In order to give the reader a better understanding of the whole building structure part of the original drawings are shown in figures 5.3, 5.4 and 5.5 below. No architectural or structural modifications were implemented for the HAP simulation purposes and all inputs used to set up the energy model were directly taken from the original project.

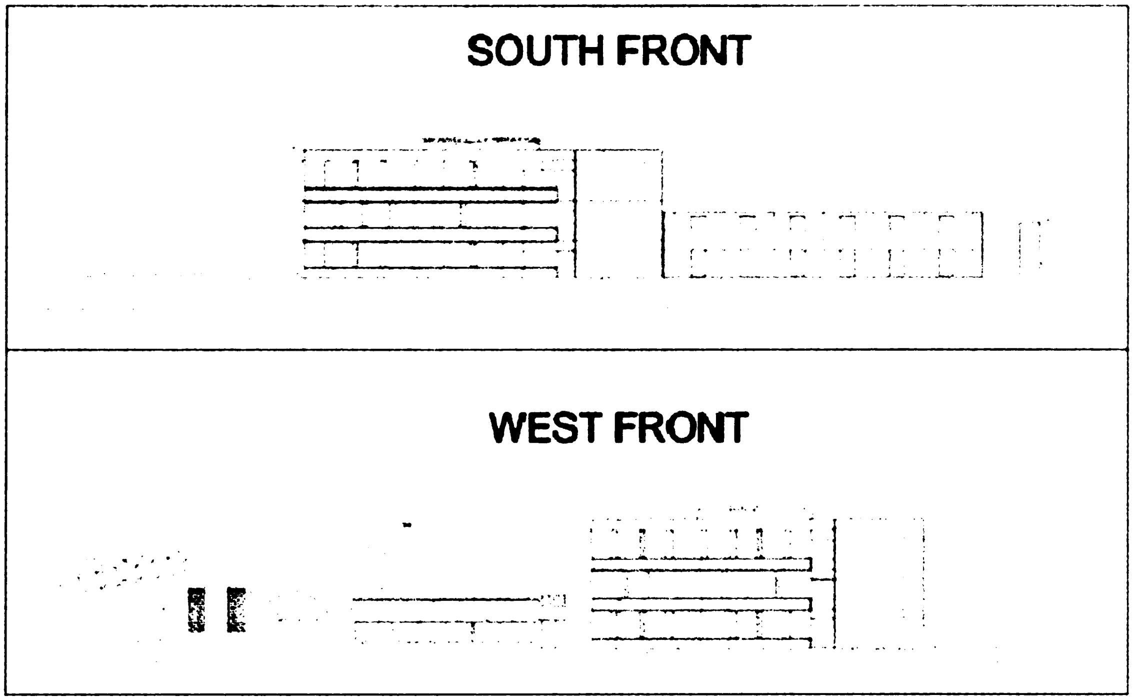

Figure 5.3: image of the Arco school project showing A-A and C-C cross sections.

Source: "KREG Engineering – ATA Group"

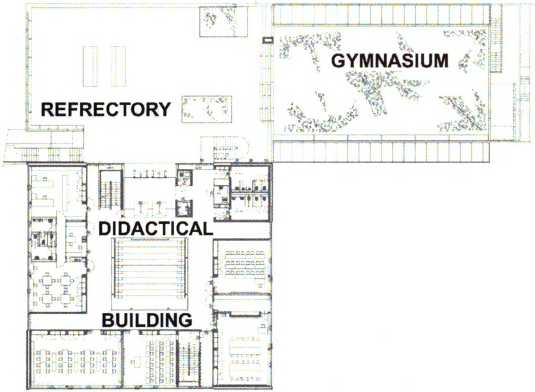

Figure 5.4: original drawing of the Arco school project showing the ground floor plant of the building.

Source: "KREG Engineering – ATA Group"

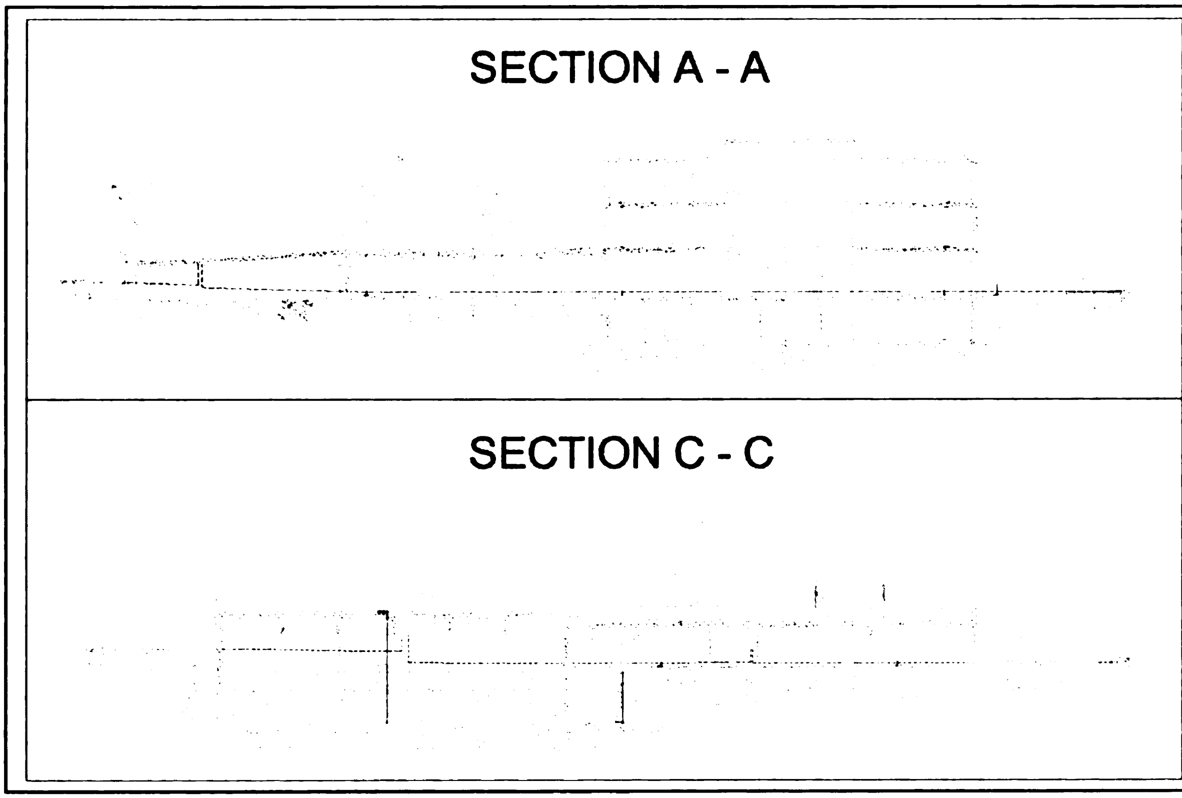

Figure 5.5: image of the Arco school project showing A-A and C-C cross sections.
Source: "KREG Engineering – ATA Group"

5.3 Whole-Building Simulation Settings.

The whole building analysis was based on the original Arco school project features. The original HAP simulation created for the Arco LEED® certification process was used as the baseline case (Entire Arco School). Another HAP simulation file considering the installation of the optimum shading device on every window was created afterwards and is referred to as the design case (entire Arco School shading). The only difference between the two cases was the presence of the shading devices over the windows, all the other characteristics of the building intended as data input in the simulation file were the same. For this reason all values related to building geometry features, air conditioning system designs, mechanical data and heating plant characteristics reported below and system designs, mechanical data and heating plant characteristics reported below and with more details in appendix D were not repeated for both design and baseline cases. The simulation was created by inputting data related to the various aspects of the building. Geometric characteristics of every space, as well as, orientation and location in the building were considered. All data related to the heating plan were input after creating an entire building heating plan. The whole building structure was divided in four thermal blocks, each of them characterized by different features referenced to the different spaces and to all mechanical aspects of each space. General information about these features are reported below. For a more detailed description refer to appendix D.

- **Entire Arco School Input Data Summary**
  - Plants Included in this Building.
  - Air Systems Included in this Building.
  - Miscellaneous Energy.
  - Meters.
  - Miscellaneous Data.
- **Arco Heating Plant Input Data Summary.**
  - General Details.
  - Air Systems served by Plant.
  - Configuration.
  - Distribution.
  - Distribution System Features.
  - Fluid Properties.
  - Primary Loop Features.
  - Secondary Loop Features.
- **Thermal Block Input Data Summary.**
  - General Details.
  - System Components.
  - Ventilation Air Data.
  - Economizer Data.
  - Ventilation Reclaim Data.
  - Central Cooling Data.
  - Supply Fan Data.
  - Duct System Data.
  - Supply Duct Data.
  - Return Duct or Plenum Data.
  - Zone Components.
  - Space Assignments.
  - Thermostats and Zone Data.
  - Supply Terminals Data.
  - Zone Heating Units.

Sizing Data (Computer-Generated).
System Sizing Data.
Hydronic Sizing Specifications.
Safety Factors.
Zone Sizing Data.
Equipment Data.
Central Cooling Unit - Air-Cooled DX.

5.4 Whole-Building Analysis – Arco Location.

Geographical Location Overview

The whole building analysis was based on the original Arco school project features located in Trentino Alto Adige, in Northern Italy. This area is unique, due to the proximity of high mountains (Dolomites) and the Garda lake, which covers a total area of about 145 square miles. Such aspects impact the local climate which is characterized by frequent precipitations during spring, fall and summer seasons and by fairly stable outdoor temperatures during the whole year, due the mitigating effect of the lake. The singularity of the area in which the Arco school building is set can be gathered from the figures reported below.

Figure 5.6: image showing the Arco School surrounding area.

Figure 5.7: image showing the Arco School construction site.

Figure 5.8: image showing the proximity between the Garda Lake and the highlighted Arco urban area.

Whole-Building Analysis Results

A primary objective of this research was to evaluate the impact of fixed shading devices on whole-building annual energy performances. However, first it is important to define the meaning of the term "energy performance", which could be seen in different ways, depending on aspects considered. For this instance researchers focused their attention on building energy performance as the total quantity of energy supplied by human infrastructures to the building in order to keep each of its activities running properly under a pre-determined annual schedule. This definition summarizes the concept of energy performance described in the ASHRAE Standard and the decision of adopting it for the current project came from the idea of considering the Arco school building from a LEED® prospective. In fact, as the sustainable protocol itself reports in EA 1 section, the percentage improvement in the proposed building performance rating has to be calculated by following the ASHRAE/IESNA Standard 90.1-2004. Following the definition cited above two different aspects of annual building energy consumption were considered, thermal energy and electrical energy respectively measured in British Thermal Units (BTU) and Kilo Watts (kW). Each building system and energy-consuming component were calculated separately for both the baseline and design cases. At the end, all values related to single items were summed together and the total annual energy consumption for the whole building was summarized in two values, the total thermal and electrical energy used. The same process was then repeated for each geographical location chosen to test the consistency of the results in other locations. In order to reduce the length of the thesis, complete tables are reported only for the Arco location, as shown in table 5.1 through 5.6 below. Tables 5.1, 5.2, 5.3 and 5.4 list annual values for HVAC components, which include cooling loads, pre-cooling coil loads, pre-heating coil loads, heating coil loads, fans, pumps and part of the boiler heating loads. All other loads and of energy consuming elements implemented in the building, such as, process loads and lighting loads, are listed under the non-HVAC components section.

Component	Baseline Case ($)	Design Case – Shading Devices ($)	Energy Cost Savings (%)
HVAC Components			
Electric	7,590	6,659	12.23
Natural Gas	3,406	3,409	0.09
HVAC Sub-Total	**10,996**	**10,067**	**8.45**
Non-HVAC Components			
Electric	26,492	26,384	0.4
Natural Gas	8,479	8,370	1.29
Non-HVAC Sub-Total	**34,971**	**34,756**	**0.62**
Grand Total	**45,967**	**44,767**	**2.67**

Table 5.1: annual cost summary table for baseline and design whole-building cases.

Here annual cost savings related to the implementation of the shading optimum solution mainly arise from HVAC power supply difference. This variation implies a percentage cost savings of 8.45% on HVAC components operating costs. This percentage is given by an annual saving for electrical supply of 12.23% and an annual loss for natural gas supply of less than 0.1%. On the other hand, the difference between non-HVAC component costs are minor totaling only about 0,77%. An important conclusion related to this first table is that implementation of fixed projecting shading devices, within the limitation of this first whole-building energy simulation, have a substantial impact on HVAC component energy costs. However, due to the order of magnitude of the grand total energy values, HVAC-related savings do not impact sensibly the whole energy costs.

Component	Baseline Case ($)	Design Case – Shading Devices ($)	Energy Savings (%)
HVAC Components			
Electric (kWh)	26,788	23,501	12.23
Natural Gas (Therm)	1,664	1,666	0.12
Non-HVAC Components			
Electric (kWh)	93,499	92,919	0.62
Natural Gas (Therm)	4,144	4,090	1.29
Totals			
Electric (kWh)	120,287	116,420	3.2
Natural Gas (Therm)	5,808	5,756	0.9

Table 5.2: annual energy consumption summary table for baseline and design cases.

Table 5.2 shows in terms of energy consumption values the same concepts previously explained for table 5.1. HVAC annual energy consumption is consistently reduced by the use of fixed shading devices (12.23 %). However, this is only a partial savings calculation, the total impact of shading devices on electrical energy annual consumption is only about 3.2 %.

Component	Baseline Case ($)	Design Case – Shading Devices ($)
HVAC Components		
Electric	0.122	0.107
Natural Gas	0.055	0.055
HVAC Sub-Total	0.177	0.162
Non-HVAC Components		
Electric	0.426	0.412
Natural Gas	0.136	0.136
Non-HVAC Sub-Total	0.562	0.548
Grand Total	0.739	0.710
Gross Floor Area (ft2)	62227.5	62227.5
Conditioned Floor Area (ft2)	33801.5	33801.5

Table 5.3: annual cost summary table per unit floor area for baseline and design cases.

Considerations previously done for tables 5.1 and 5.2 are also reflected in table 5.3 which shows the impact of shading device use on annual energy costs on a square foot basis. Once again the energy costs per square foot of the Arco school building are considerably lower for only the HVAC system, and they are slightly lower for the whole-building energy consumption values.

Component	**Baseline Case ($)**	**Design Case – Shading Devices ($)**
HVAC Components		
Electric	16.5	14.8
Natural Gas	7.4	7.6
HVAC Sub-Total	**23.9**	**22.4**
Non-HVAC Components		
Electric	57.6	58.8
Natural Gas	18.4	18.8
Non-HVAC Sub-Total	**76.1**	**77.6**
Grand Total	**100.0**	**100.0**

Table 5.4: whole-building summary table for baseline and design cases showing component cost as a percentage of total cost.

Table 5.4 above demonstrates an important aspect of energy savings caused by the use of fixed shading devices. The importance of each system component on the whole-building energy consumption rates varies as a function of the shading device configuration. More specifically, for the design case simulation HVAC components have a smaller impact on annual energy consumption, whereas non-HVAC components provide a larger impact.

End Use	Design Energy Type	Proposed Design Units	Baseline Building Results	Proposed Building Results	Percent Savings (%)
Interior Lighting	Electric	Energy kWh	20,228	20,228	0.0
		Demand kW	17.7	17.7	0.0
Space Heating	Electric	Energy kWh	730	731	-0.1
		Demand kW	1.5	1.4	6.7
Space Heating	Natural Gas	Energy Therm	1,664	1,666	-0.1
		Demand MBH	348.4	328.3	5.8
Space Cooling	Electric	Energy kWh	11,690	9,861	15.6
		Demand kW	20.9	17.1	18.2
Fans - Interior	Electric	Energy kWh	13,569	12,103	10.8
		Demand kW	3.7	3.3	10.8
Process energy	Electric	Energy kWh	26,319	26,319	0.0
		Demand kW	12.3	12.3	0.0
Service water heater	Natural Gas	Energy Therm	4,144	4,144	0.0
		Demand MBH	273	273	0.0
Elevator	Electric	Energy kWh	10,699	10,699	0.0
		Demand kW	5	5	0.0
Exterior lighting	Electric	Energy kWh	4,380	4,380	0.0
		Demand kW	1	1	0.0
Energy Totals	Total Annual Energy Use kBTU		991,218	980,138	1.1
	Annual Process Energy kBTU		235,056	235,056	0.0

Table 5.5: performance rating summary table for baseline and design cases showing energy consumption values of each building component.

Table 5.5 shows the impact of shading device use on each energy consumption category for each system component considered in the whole-building simulation. Values are related to their specific energy source, either electric or natural gas. Major savings are related to electrical consumption, especially for space heating and cooling components and for interior fan systems. Taken one at a time, each of these energy saving values seem consistent. Energy use for cooling interior spaces decreases by 15.6%, and the energy used to run the interior fan system decreases by 10.8%. However, energy reductions for other gas based systems are not as large as shown in the final summary table 5.6 below.

Energy Type	Baseline Design			Proposed Design			Percent Savings	
	Energy Use		Cost ($)	Energy Use		Cost ($)	Energy Use	Cost
Electric	120.287	kWh	34.082	116.420	kWh	32.988	3,2	3,2
Natural Gas	5.808	Therm	11.885	5.756	Therm	11.779	0,9	0,9
TOTAL (Model Outputs)	991.218	kBTU	45.967	972.592	kBTU	44.767	2,6	2,6

Table 5.6: annual energy consumption summary table for baseline and design cases located in Trentino.

5.5 Whole-Building Analysis – Multiple Locations.

In order to test the validity of the results and to see if they were dependent on this specific location the researcher evaluated the same baseline and design case buildings in three other locations in southern Europe. The whole-building energy models were tested for various locations which varying weather conditions, latitude and morphological aspects of the surrounding areas. Three other European cities were chosen as case-study locations including: Naples (Italy), Valencia (Spain) and Frankfurt (Germany). Figure 5.9 reported below shows a map of Europe with the four location selected for the whole-building simulation.

Figure 5.9: map of Europe showing locations of Arco, Valencia, Naples and Frankfurt.
Source: Alabama Maps – website.

Naples – Italy –

The choice of Naples as one of the locations was determined by considerations specifically related to varying weather conditions, latitude and the morphological aspects of the surrounding areas.

The city of Naples is located in the south part of Italy, by the Mediterranean sea coast. Its location is almost flat, and is substantially different from the conditions set for the previous model, situated in the Alps. Moreover, weather conditions of Naples are very different from the previous ones due to its proximity to the Mediterranean sea.

The whole-building energy simulation for Naples conditions was run for both design and baseline cases, always considering the first as the one with fixed shading devices, the second as the original Arco school design. Also for Naples, as for each location considered, all analysis and result categories cited for chapter 5.3 were performed. Only a summary is reported here, the complete results for whole-building multiple locations is reported in appendix E. The goal of this section is to provide a general overview and summary related to total annual energy consumptions, as shown in table 5.7 below.

	Proposed Design			Baseline Design			Percent Savings	
Energy Type	Energy Use		Cost ($)	Energy Use		Cost ($)	E. Use	Cost
Electric	120,514	kWh	34,146	117,181	kWh	33,202	2.8	2.8
Natural Gas	5,817	Therm	11,903	5,814	Therm	11,898	0.1	0.0
TOTAL (Model Outputs)	992,049	kBTU	46,049	981,242	kBTU	45,100	1.1	2.1

Table 5.7: annual energy consumption summary table for baseline and design cases located in Naples.

The energy simulation results were similar to those of the Arco whole-building analysis. Energy savings of 2.8 % from annual electrical energy consumptions is somewhat offset by small natural gas savings. However, once again the use of fixed shading devices substantially impacted the annual electrical energy consumption related to HVAC components. Under this design case results showed an annual electrical energy cost of $10,129 against the $ 11,078 of the baseline case. In other words an annual electrical energy saving of 8.5%, very similar to the 8.45% previously obtained for the Arco location. These savings are also reflected in the total electrical energy consumption which goes from the 120,514 kWh of the baseline case to the 117181 kWh of the design case with a percentage saving of 2.7 %.

Valencia – Spain –

This specific location was chosen to confirm the results obtained for the previous location. From many points of view Naples and Valencia are two similar cities. Both are located by the Mediterranean at approximately the same latitude and also have similar the morphological characteristics. However, weather conditions are different, especially when considering precipitation and cloud cover. In fact, Valencia is surrounded by a small mountain chain that keeps most of all atmospheric disturbances away from the city area. This yields higher sun exposure and solar gains in buildings.

The whole-building energy simulation was conducted following the previous model settings. No major changes were noticed between the Naples and Valencia models. Total energy consumption calculated on annual basis was similar, with some minor variation in a 0.2 % range. Also annual total cost savings between baseline and design cases were similar with, 2.7 % for Valencia against the 2.8 % for the previous location. Summary values are reported in table 5.11 below.

	Proposed Design			Baseline Design			Percent Savings	
Energy Type	Energy Use		Cost ($)	Energy Use		Cost ($)	E. Use	Cost
Electric	120,389	kWh	34,111	117,181	kWh	33,202	2.7	2.7
Natural Gas	5,812	Therm	11,893	5,814	Therm	11,898	0.0	0.0
TOTAL (Model Outputs)	992,948	kBTU	46,004	981,242	kBTU	45,100	1.2	2.0

Table 5.8: annual energy consumption summary table for baseline and design cases located in Valencia.

As detected for the previous cases, the main energy savings were related to electrical energy consumptions, especially for HVAC systems. In terms of costs, the optimum shading device led to an annual 9 % saving for HVAC component electrical energy consumption. This was reflected in the total annual electrical energy consumption as a 2.76 % saving resulting from the difference between the 120,389 kWh of the baseline case and the 117,181 kWh of the design case.

An interesting observation is that electrical energy savings calculated for the original Arco locations resulted in higher savings than the ones found for Naples and Valencia locations. The main elements that affect electrical savings are HVAC components and, more specifically cooling loads. Because of these considerations researchers expected higher electrical energy savings for warmer weather locations but analysis didn't reflect this prediction. In order to partially verify these results researchers decided to pick a northern Europe city as the last whole-building location test. The city chosen was Frankfurt in central-western Germany.

Frankfurt – Germany –

Based on the consideration listed above the whole-building energy model was run on the basis of Frankfurt area settings. In this case, the characteristics of the area are similar to the Valencia case, except for the proximity to the sea. The height above sea level is the same, as well as, the morphology of the surrounding area and the urban area extension. Researchers didn't pick a location in the north of Europe, such as Norway or Sweden for example, because weather conditions would have been too different from those of Arco. The building was originally designed to perform in the northern Italian area. Drastic weather and location changes could heavily impact the building response not only from an energy consumption standpoint but also for other aspects such as material or window-floor area required ratio values.

For this case the results met the researcher's original expectations. The total electrical energy consumption calculated on an annual basis decreased by approximately 1 %. In fact, looking at Naples case-study annual consumption values for electrical energy went from 120,514 kWh to a 119,391 kWh. Moreover, natural gas saving values related to the implementation of fixed shading devices were negative. The issue is explainable by considering solar gains which provide heat to the building. In the Arco school building natural gas is used to produce heat during winter. Fixed shading devices stop part of the solar radiation that heats the building and, because of that, they have a positive effect during the summer but a negative impact during winter. The loss of solar heat caused by the implementation of the shading devices is reflected by the increment of natural gas consumption in the design case. However, both in terms of cost and energy performance, energy savings from reductions in cooling load during the summer period exceeded the heating looses during the winter period. This consideration is demonstrated by the total annual energy savings values which reached 1.9 % for both energy use and cost parameters. Table 5.9 below reports the summary values for the present case-study.

	Proposed Design			Baseline Design			Percent Savings	
Energy Type	Energy Use		Cost ($)	Energy Use		Cost ($)	E. Use	Cost
Electric	119,391	kWh	33,828	116,218	kWh	32,929	2.7	2.7
Natural Gas	5,817	Therm	11,904	5,828	Therm	11,926	-0.2	-0.2
TOTAL (Model Outputs)	989,071	kBTU	45,732	979,312	kBTU	44,855	1.0	1.9

Table 5.9: annual energy consumption summary table for baseline and design cases located in Frankfurt.

Whole-building analysis results for different location are summarized in figure 5.10 below.

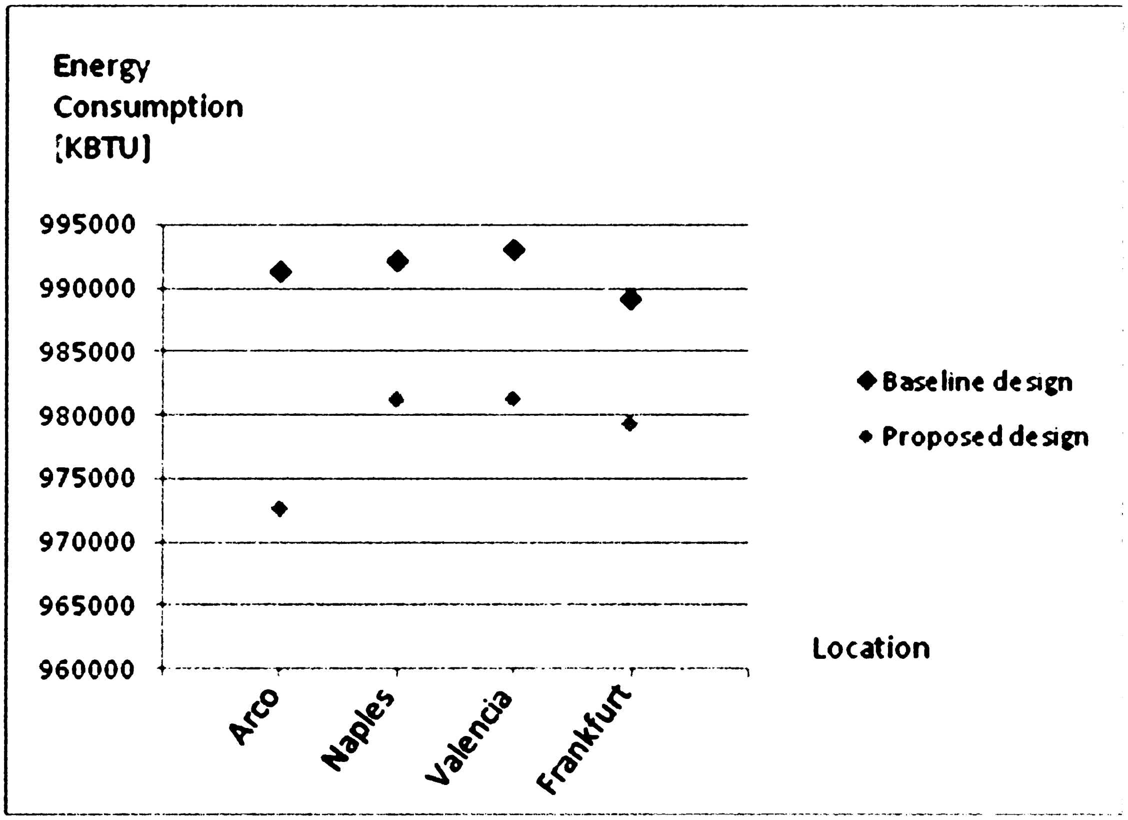

Table 5.10: annual energy consumption summary graph for baseline and design cases related to Arco, Naples, Valencia and Frankfurt locations.

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5.6 Chapter summary

Chapter Five describes the whole-building analysis process used by the researchers. The original whole-building characteristics related to the Arco project that were used as input files for the energy simulation are reported. The chapter also describes the choice of the several geographical locations selected to help validate the whole-building analysis. Analysis results obtained from different whole-building energy simulations, each of them located in different areas, are reported, explained and compared.

– CHAPTER 6 –

CONCLUSIONS AND SUMMARY

6.1 Introduction.

Chapters Four and Five addressed the single space analyses and whole building analyses respectively. This final chapter addresses conclusions and recommendations that the researchers drew from the research, discusses limitations of the study and suggests areas for future research.

6.2 Single-Space Analysis.

6.2.1 Single-Space Analysis Limitations

The impact of fixed shading devices on single-space energy use varies as a function of the space design characteristics, window proportion and thermal mass. Four single-space analysis were performed in order to identify the optimum solution for shading devices in relation to window configuration. Results varied as a function of window configuration. In some cases, such as with the single and multiple 5-by-6 feet punctured window spaces, gaps between energy consumption values were even bigger because of the secondary effect of thermal mass. These considerations led researchers to focus on the single-space result limitations and the range of applicability of the results. They concluded that the impact of fixed shading devices on single-space energy consumption can not be generalized to all types of single-space designs. However, they can be considered valid for categories of single-space design. The main design features that characterized the sample single space were the floor area, the window area, the orientation and the geometrical shape. From a design point of view, the single space used as a case-study is a middle-school classroom characterized by standard features. In Italy, as well as in Europe and in the US, classroom spaces are required to have a maximum occupancy coefficient which establishes the maximum ratio between area and number of students. Codes require classrooms to be designed with a minimum window-floor area ratio, as well as, minimum lighting levels, air flow rates and air conditioning systems. From this point of view, the single space selected to determine the shading device optimum solution could be considered common and certainly standardized. Therefore, results obtained from the single-space analysis could be implemented as general guideline by project teams that are designing a classroom similar to the one used for the present research.

Another point that has to be considered is the impact of thermal mass on energy consumption. The concept of thermal mass is strictly related to the density of material used, the ratio between window and wall surface and the ratio between space volume and total space contact area intended as the sum of all walls, windows, floor and ceiling areas. However, national codes fix the values for all these coefficients except for the density of the material used. That aspect is a function of the material type and can vary from case to case. While the study did address changes in thermal mass, there were primarily the result of changing window size and not construction systems. This study did not address changes in construction type (i.e from heavy construction to light construction) so the results and conclusion are not necessarily valid for "light" buildings. Further research would be necessary to address changes in construction type.

Another issue is related to the specific location that was chosen to run the single-space analysis. As previously explained in chapter Three, all single-space simulations had the city of Arco as location input data. From the HAP software point of view, the main aspect that affects the single-space model is the latitude, which is related to the sun irradiance angle in different periods of the year. For the scope of this thesis researchers didn't verify the impact of such variable on the single-space analysis results. Therefore, all values obtained can be considered valid only for single space simulation characterized by the same latitude of Arco. However, the researchers did explore this impact later during the whole building analysis.

6.2.2 Single-Space Analysis Conclusions.

On the basis of these considerations, information obtained from the single-space analysis that could be used for other cases are:

- **Qualitative impact of fixed shading devices on single-space annual energy consumption.** All single-space analysis developed during the present research showed that a single space without shading devices requires more energy than a space characterized by shaded windows. This effect is caused by the positive impact of shading devices on cooling loads during the summer which resulted always larger than the negative impact on heating loads during the winter. In other words, the implementation of fixed shading devices improves single-space annual energy performances.
- **Qualitative identification of fixed shading device characteristics for obtaining best annual energy performances.** Single-space analysis results showed that shading device projection length is the most impacting variable for energy consumptions. As explained in the previous paragraph, the main improvement arises from the cooling gains obtained during the summer period. Therefore, fixed shading devices with a length range between 40 and 60 inches led to better energy performance that shorter ones.
- **Identification of the best combination of geometric variables for fixed shading devices.** On the basis of the considerations reported in chapter four

the optimum shading device that led to the highest annual energy savings for the single-space had a length of 56 inches, an extension beyond window borders of 4 inches and a distance from the top window border of 12 inches.

- **Quantitative identification of the percentage savings introduced by the implementation of the optimum shading device solution on the basis of annual energy consumption.** For this research researchers considered only the last two case-studies, in which thermal mass had only smaller impact. Here values of savings for annual energy consumption ranged between 8.1 % of the five 5-by-6 windows space and the 13.7 % of the single 31-by-6 window space. However, these values represent the energy consumption gaps between optimum shading devices use and spaces without shading devices. Within the range of shading device use the difference between the optimum and the worst combination of variables was 2.4 % for the five punctured windows and 8.7 % for the single wide window. Specific values of all single-space analysis are reported in appendix C.

6.3 Whole-building analysis

The whole-building simulation process was described in chapter Five. In order to identify the information that could be used as reliable conclusions for future projects, researchers focused on the limitations of the specific experiment. On the basis of these limitations, a list of general conclusion was developed.

6.3.1 Whole-Building Analysis Limitations.

A primary limitation of the research was the use of a single case-study building. Other building conditions and configurations could have led to other possible results. The main variables that could affect analysis and conclusions are building design and location.

From the design point of view, the Arco school could be considered typical for the region. Shapes of either single rooms and of the entire complex are simple and squared. Moreover, as previously explained in section 6.1 for single-space limitations, geometric features of educational institutions are heavily standardized by local and governmental codes. However, other aspects, such as, high window configuration and space orientation are specifically related to this single project. Final conclusions about the whole-building simulation results certainly won't be valid for all possible school building designs. Therefore it's important to identify some key elements of the building that affected the energy model analysis and that could be used as reference parameters to calibrate the applicability of final conclusions. For the scope of the analysis, researchers identified the following main categories:

- Space design related elements: floor area, ceiling height, building weight, average light consumption (Watts per Square Foot), space occupancy, type of activities performed, wall/window area ratio, type of walls and interior partitions.
- Mechanical system related elements: thermostat cutoffs, thermal efficiency, ventilation system type, operating schedule, heating plant settings, cooling system components.

Specific values related to the whole-building analysis input data are reported in appendix D. Future project teams will be able to implement the whole-building analysis information listed below only after comparing the proposed design with the Arco school project.

Under the whole-building analysis section the researcher considered cost savings only as total annual energy cost reduction. The analysis of costs related to installation and maintenance of fixed projecting shading devices was not in the scope of this research and therefore it was not taken into account.

Another aspect that has to be considered prior to drawing final conclusions is the limited number of locations investigated. In order to prove the consistency of the data obtained the whole-building simulation was run for four locations, intended as weather conditions and geographical coordinates. Researchers chose four cities respectively located in Italy, Spain and Germany. For each simulation output values were considered; the total annual energy cost, the total energy consumption and the annual cost of each mechanical system component. The considerations related to final results and reported in the next paragraph were confirmed by all four simulations. However, results can not be considered valid for all location inside the selected countries. The fact that all four analysis results coincide gives researchers a high probability, but not the certainty, that same considerations could be applied to contiguous locations.

6.3.2 Whole-Building Analysis Conclusions.

On the basis of these considerations, information obtained from the whole-space analysis that could be implemented for other cases are:

- **Qualitative and quantitative impact of optimum fixed shading devices on whole-building energy consumption.** All energy simulations conducted for the whole-building model implementing fixed shading devices characterized by the optimum combination of variables showed an annual energy consumption improvement. Percentage savings obtained from the analyses ranged between 1.1 % and 2.6 %, considering all kinds of energy use of the building. Two different energy sources were considered for the whole-building supply; natural gas and electrical energy.
- **Qualitative and quantitative impact of optimum fixed shading devices on system components.** Percentage savings resulting for whole-building total energy consumption proceeded from annual energy savings of each group of system components. Two main groups were identified; HVAC and non-HVAC devices. HVAC components included cooling loads, pre-cooling coil loads, pre-heating coil loads, heating coil loads, fans, pumps and part of the boiler heating loads. All other loads and of energy consuming elements implemented in the building, such as, process loads and lighting loads, were listed under the non-HVAC components section. As HAP analysis results showed, the impact of fixed shading device implementation is different for different system components. The highest shading device impact was noticed for the annual electrical energy consumption HVAC. Under this point, percentage savings calculated for the four case-studies ranged between the 8.15 % of the Valencia simulation and the 8.63 % of the Frankfurt simulation.

These values were interpreted by researchers as the consequence of shading device impact on cooling loads during the summer period. On the other hand, savings related to annual consumption of natural gas, which in the Arco project was mainly used for heating purposes, didn't undergo any considerable changes. Percentage savings related to natural gas annual consumption ranged between - 0.2 % and 0.9 %. It is important to highlight the negative value obtained for the Frankfurt case-study. Researchers interpreted this as the consequence of heating losses caused y the implementation of shading devices during the winter period. Especially in northern areas characterized by rigid winter temperatures, heating gains caused by direct solar irradiation play an important role in whole-building energy balance. The presence of fixed shading device has a negative impact on solar gain. However, such losses are abundantly overbalanced by cooling gains during the summer related to HVAC electrical energy consumption.

- **Qualitative and quantitative impact of optimum fixed shading devices on electrical energy consumption.** Performance improvements highlighted for HVAC energy consumption are reflected also on the total annual building electrical energy balance. Under this particular point, savings due to shading device use ranged between the 2.7 % for the Valencia case-study and the 3.2 % for the original Arco simulation. These values are substantially smaller than the ones cited above for the single HVAC electrical consumption and that is explainable by considering building process and lighting loads. In fact, these types of loads cover an important part of the total electrical energy consumption and they were considered constant for all simulations analyzed.

More specific data related to electrical energy consumption values are reported in appendix D.

6.4 Development of Researcher Recommendations

On the basis of these considerations, the following recommendations are made for researchers as follows:

- Investigate the types of loads that could be affected by the implementation of fixed projecting shading devices.
- Determine general rules and equations applicable to whole-building systems to quantify the impact of fixed shading device impact on cooling loads versus heating loads.
- Determine the qualitative and quantitative impact of fixed shading device use on different types of energy sources in relationship to mechanical system settings.
- Determine optimum weather conditions and geographical location which could maximize the positive impact of the fixed shading device use on whole building energy performance.

6.5 General Conclusions

All work done for the present thesis increased the researcher's knowledge and confidence in shading-device-related issues. Information has been used to explore their impact on energy use. The researchers have developed the following conclusions about the impact of fixed shading device on building energy performance.

- The implementation of fixed shading device has a positive impact on building energy performance and glare-related issues. All simulation results showed the increment of energy savings due to the implementation of such devices. On the other hand, glare control issues were not considered within the scope of the research but fixed shading devices certainly constitute one possible way to adjust them.
- Shading devices could possibly have also negative impact on daylight parameters. This issue was not specifically tested during the research but is implied by the literature.
- Implementation of fixed shading devices is strongly recommended in buildings characterized by large cooling loads and cooling-related mechanical systems.
- Longer projections of shading devices lead to better energy performance compared to short-projecting ones.
- Overall impact of shading devices is closely related also to window size and configuration, as well as, thermal mass characteristics of the building.

6.6 Impact of Fixed Shading Devices on LEED® Buildings.

The use of fixed shading devices has a positive impact on achieving LEED® credits. The main advantages arise from whole-building energy savings calculated on an annual period basis. The initial baseline case simulated for the original Arco School design showed a total annual energy consumption of 1,867,656 kBTU. In this case, the whole building was set up using basic default parameters assigned by LEED®, in accordance with the ASHRAE 90.1. On the other hand, the Arco School proposed design showed a total annual energy consumption of 991,218 kBTU with a comprehensive annual saving of 47 %. Implementation of fixed shading devices showed an additional annual percentage energy saving of 2.6 % with reference to the proposed design. As the LEED® ranking list for energy savings shows, values of annual savings have a superior order of magnitude. For example, the proposed Arco School building earned 10 credit points exceeding 42% of annual energy saving. However, even a small gain such as the one due to shading device use could be very useful for the scope of the LEED® certification helping designers to achieve better energy performance levels.

Researchers found that, for LEED® purposes, use of fixed shading devices should not be considered as a major-effect element that heavily impacts the whole building accreditation process. However, it should always be considered as a possible solution to earn potentially one to two additional point under the EA Credit 1 section.

6.7 Areas for Future Research

The present research investigated a very specific element related to the use of fixed shading devices. Therefore, this thesis has, as previously explained, many limitations that were already considered throughout the whole text. However, limitations can also be seen as opportunities to develop other research studies and eventually to validate the information discussed previously. From this point of view, researchers considered the following fields.

Analysis results showed that annual energy savings due to fixed shading device use result from cooling gains during the summer period. However, fixed shading devices have a negative impact during the winter period due to the sun heating losses that they cause. An interesting aspect could be the impact of movable shading devices on whole-building performance. Movable devices could provide both cooling gains during the summer and heating gains during the winter. Theoretically this solution should have a positive impact on the whole-building energy balance and other researchers could focus on how effective this solution could be in terms of percentage savings. For the scope of the present research the whole-building analysis were run for a limited number of locations. As already explained above, researchers can not extend the applicability of the results to different locations. However, all data implemented for the current whole-building analysis could be used as a platform to run other energy simulations with different location settings. This operation would integrate the work done for the present research and will also assign a higher value to all data obtained.

Another area of interest for future research is related to building design. For the present thesis the Arco school building was chosen as a case-study design and tested under different conditions. Using the conclusions of this work as a starting platform, other researchers could apply the same process to different building designs in order to verify how fixed shading devices could impact whole-building energy consumption for various designs. Depending on the results obtained, researchers could then identify some main design parameters that affect the impact of shading devices on energy performance.

6.8 Chapter Summary.

In this chapter researchers summarized and explained the most important conclusions identified during the research. Considerations of limitations and area of future research are also presented.

– APPENDICIES –

– APPENDIX A –

The LEED® System

A.1 The LEED and USGBC Background

During the early 1990's the green building movement begun to take hold. The hopes of the American Society of Testing and Material (ASTM) of creating a sustainability standard failed. The movement's supporters begun looking for an alternative organization willing to develop a rating system. The U.S. Department of Energy became an ally of green building followers and by 1996 had contracted with Public Technology, Inc. (PTI) and United States Green Building Council (USGBC) to develop the "*Sustainable Buiding Technical Manual: Green Building Design, Construction and Operations*" (PTI 1996). The manual was written under contract, including editorial contributions from people closely aligned with USGBC. The first paragraph of the Manual furnishes a good idea of how this movement was conceived:

Public Technology, Inc. developed this manual to address the growing demand for information on the design and construction of green buildings. The manual was jointly sponsored by PTI's Urban Consortium Environmental and Energy Task Forces. The U.S. Green Building Council (USGBC) worked with PTI to develop the manual. David Gottfried of Gottfried Technology Inc., served as managing editor. An Advisory Committee of local-government and private-sector representatives assisted in developing the manual. The manual underwent a consensus review process by members of the USGBC and was peer reviewed by U.S. DOE and U.S. EPA officials.

Source: *"American Wood Council" website – www.awc.org*

The Leadership in Energy and Environmental Design (LEED) rating system is a credit-driven assessment program for rating new and existing commercial, institutional, and high-rise residential buildings. Evaluation of environmental performance is made from a "whole building" perspective over a building's life cycle, and a standard scale is provided to define what constitutes a "green building."

These overall ratings are awarded based on how many points are accumulated. Assessment and point scoring is conducted by LEED accredited designers. USGBC also accredits these design professionals and provides third-party review of the building's compliance with LEED.

A.2 LEED Overview

The LEED Green Building Rating System was developed by the U.S. Green Building Council as a voluntary, consensus-based national standard for developing high-performance, sustainable building projects. According to USGBC, LEED was created for the following reasons:

- Facilitate positive results for the environment, occupant health and financial return
- Define "green building" by establishing a common standard for measurement
- Prevent "greenwashing" (false or exaggerated claims)
- Promote whole-building, integrated design processes
- Recognize environmental leadership in the building industry
- Stimulate green competition
- Raise consumer awareness of green building benefits
- Transform the "building market"

Source: Northeast Waste Management Officials' Association website (http://www.newmoa.org)

A wide variety of benefits can be achieved by building green buildings to comply with LEED. These benefits include energy savings, economic benefits, improved health of building occupants and conservation of precious resources. Benefits range from being fairly predictable (energy, waste and water savings) to relatively uncertain (productivity / health benefits).

The LEED system utilizes a list of performance based "credits" worth up to 69 points. Organizations pursuing LEED certification voluntarily adopt and document compliance with selected standards, and upon achieving various thresholds of compliance, step levels of LEED certification ratings are achieved. There are 4 prerequisite areas that every building must meet and several credit options in each area. These 69 credits are divided into six categories: Sustainable Sites (SS); Water Efficiency (WE); Energy and Atmosphere (EA); Materials and Resources (MR); Indoor Environmental Quality (IA); and Innovation & Design Process (ID). In order to attain LEED certification, a minimum of 26 points must be achieved. A Silver rating is achieved by earning between 33 and 38 points, Gold between 39-51 and Platinum between 52 and 69 points. The distribution of points by general category is shown in Tables 1.1 – 1.2 – 1.3 below. This could be considered as the main LEED organic structure.

The LEED classification systems had been developed under the supervision of USGBC committees, in relationship with the USGBC politic and processes. Some differences between the definition and further application of each credits come up depending on the considered building. The most general one is the LEED NC (New Construction) that relies up to 69 credits. It is just one more product between the whole range of classification systems that are taking place among the LEED world. These files could be summarized as follows:

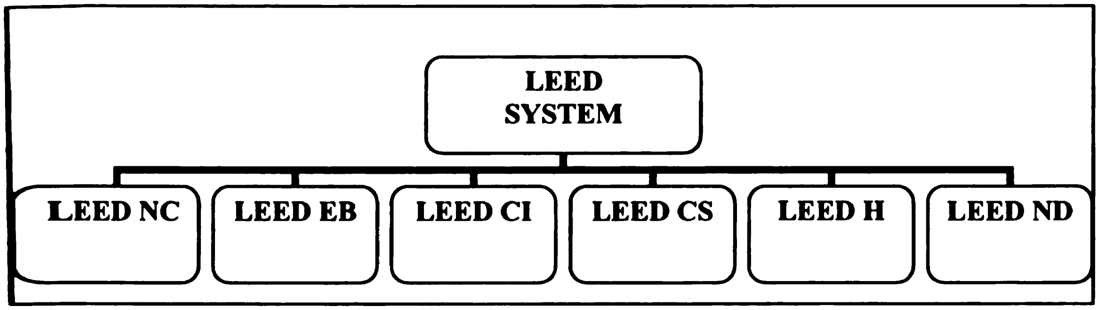

Figure A.1: LEED System organization

Source: www.usgbc.org (visited on 17th February 2008)

Credits		Points	%
8	Sustainable Sites (SS)	14	22%
3	Water Efficiency (WE)	5	8%
6	Energy and Atmosphere (EA)	17	27%
7	Materials and Resources (MR)	13	20%
8	Indoor Environmental Quality (IQ)	15	23%
		64	
	Design Process and Innovation (ID)	4	
	LEED Accredited Professional	1	
	Total Points Available	69	

Table A.2: LEED NC Point Distribution

Source: LEED NC v. 2.2 Reference Manual

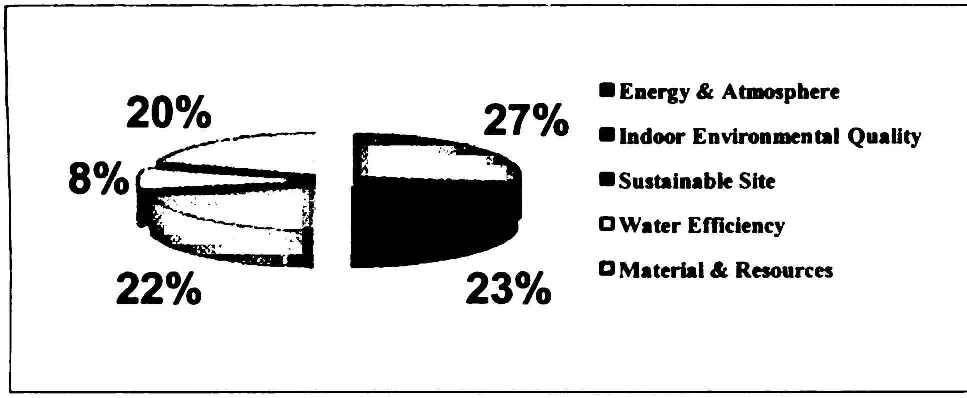

Figure A.3: *LEED Credit Categories*

Source: www.usgbc.org *(visited on 17th February 2008)*

Certification Level	**Required Points**
Certified	26-32 points
Silver	33-38 points
Gold	39-51 points
Platinum	52+ points
	69 possible points

Table A.4: LEED Certification Levels

Source: USGBC 4, 2005

The following lists were extracted from the LEED NC reference manual and describes the principal concepts of each chapter:

LEED SS Credits: are designed to develop only appropriate sites, reuse existing buildings and / or sites, protect natural and agricultural areas, reduce the need for automobile use and protect and / or restore natural sites. The principal arguments covered under this chapter are:

- Construction Activity Pollution Prevention;

- Site Selection;
- Development Density & Community Connectivity;
- Brownfield Redevelopment;
- Alternative Transportation: (Public, Bicycle Storage, Low Emitting & Fuel Efficient Vehicles, Parking Capacity);
- Site Development;
- Storm water Design;
- Heat Island Effect;
- Light Pollution Reduction.

LEED WE Credits: aim to reduce the quantity of water needed for a building and to reduce municipal water supply and treatment burden. The main arguments covered under this chapter are:

- Water Efficient Landscaping;
- Innovative Wastewater Technologies;
- Water Use Reduction;

LEED EA Credits: are based on the main idea of building energy performances. The compliance with them provides a high-efficiency energy-use performance for the building and for its utilities. The main arguments covered under this chapter are:

- Commissioning Authority and Commissioning Process (accounted as a system-and-building check-up team)
- Minimum Building Energy Performance
- Refrigerant System Management
- Energy Performance Optimization

- On-Site Renewable Energy Use
- Measurement & Verification Approach
- Renewable Energy Use

LEED MR Credits: support the appropriate evaluation and choice of materials used inside the building, either for design, construction, health and recycling issues. The main arguments covered under this chapter are:

- Recyclables Materials and Systems
- Building Reuse
- Construction Waste Management
- Materials Reuse
- Use of Regional Materials
- Use of Renewable Materials
- Use of Certified Wood

LEED EQ Credits: are pointed toward the building indoor quality improvement. An effort to achieve a high quality standard for the indoor environment based on air quality, pollutant avoidance and chemical products use. The main arguments covered under this chapter are:

- Tobacco Smoke Control
- Air and Ventilation Monitoring
- Use of Low-Emitting Materials
- Pollutant Source Control
- Thermal Comfort Systems

LEED ID Credits: are designated to push all constructions toward the use of new technologies, ways and methods to improve the building performance. Under this chapter are also considered the assignment of extra point due to some high performance achievement under the previous credit chapters. Except for these last ones the main arguments covered under this chapter are:

- Innovation in Design
- Presence of a LEED Accredited Professional

– APPENDIX B –

Implementation of the LEED® System.

B.1 The LEED World-Wide Status to Date.

The LEED system has been growing up very quickly during the last years, starting from a national dimension it founded a very positive international feedback. Every country, after the early creation of the US GBC, started developing their own Green Building Councils.

The World GBC held its founding meeting in November of 1999 in San Francisco, California USA, with eight countries in attendance including:

- U.S. Green Building Council;
- Green Building Council of Australia;
- Spain Green Building Council;
- United Kingdom Green Building Council;
- Japan Green Building Council;
- United Arab Emirates;
- Russia.

Source: World GBC - www.worldgbc.org (visited 02/27/2008)

Global awareness of the urgent need to reduce greenhouse gas emissions and other environmental degradation mandates the rapid formation of green building councils around the world. Buildings are responsible for 40% or more of greenhouse gas emissions in the developed world (*www.worldgbc.org*).

The World Green Building Council was created as a union of national councils whose mission is to accelerate the transformation of the global property industry towards sustainability.

World GBC members have been leading the movement that is globalizing environmentally and socially responsible building practices. Its objective is to rapidly build an international coalition that represents the entire global property industry. Now a day the World GBC is a business-led coalition. Green Building Councils are consensus-based not-for-profit organizations with no private ownership, and diverse and integrated representation from all sectors of the property industry. Business are considered as a powerful solution-provider, and the main purpose will be to improve frameworks that harness business's ability to deliver. Another important goal of the World GBC is to coordinate efforts with other international forces to optimize everyone's effectiveness. World GBC has partnered the Clinton Climate Initiative (CCI), and supports UNEP's Sustainable Building and Construction Initiative, and the World Business Council on Sustainable Development's Zero-energy Buildings Project.

In Europe, Spain already created its own GBC in 1996 and now Italy is following the same path, starting from some prototype-projects in the Trentino Region. Also in the "Old Continent", especially concerning public and important projects, many countries and companies are now leading toward massive green building construction, that is caused by the always increasing needs of sustainability and, on the other hand, by the wish of these companies and countries to improve their image by developing sustainable and therefore innovative buildings.

Some statistical data concerning the Canadian LEED system (one of the most representative ones) growth during the last years are given below in order to support these claims. Its development is fairly larger in the US (when it started in the early 90ies) rather than in the rest of the World. Despite of that numbers and information are typically the ones of an international relationship with LEED strong of a constant increase of budget, constructions and governments involved.

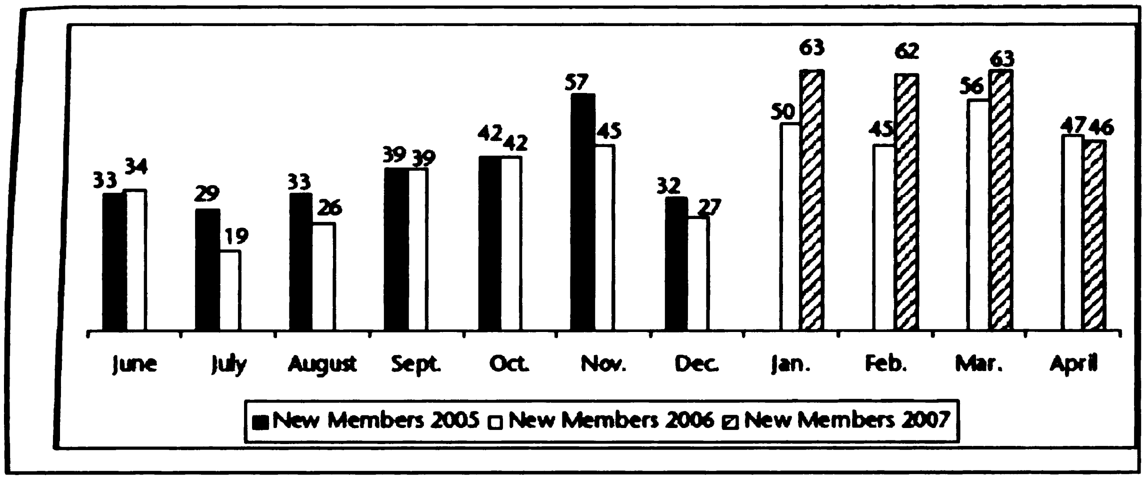

Figure B.1: CaGBC membership growth by month (last update May 2007).
Source: www.worldgbc.org/docs/Canada.ppt (visited 03/20/2008).

These new construction systems and technologies are experiencing rapid growth. For this main reason the research team decided to focus on LEED and its potential development. From a professional point of view the relative newness of these Councils and certification systems is opening a large number of potential development and growth fields. However, they still present some weaknesses and substantial problems that need to be solved. The well-established presence of the US Green Building Council has already developed out guidelines that other institutions could, and in some cases will have to, follow. Especially for the very recent councils, different realities of different countries will have to be compared. The presence of specific laws and requirements strongly affects the approach to the LEED system and therefore, could become very difficult and complicated under certain conditions. One of the main concepts that will have to be considered for the development of this research project is the current need of comparison guidelines that could support the

European use of the LEED protocol, with respect to the US Green Building Council standards.

After consulting some authoritarian parties, such as Spanish GBC experts, faculty professors and LEED A.P. professionals, leading to a preliminary analysis of the potential issues, the four basic problems that currently can be identified in Europe are:

1. The need for developing a "Commissioning System" similar to that in the USA. Legal, institutional and occupational comparison between the two different social and professional structures and creation of a standard process model showing how this professional task could be exported to the European system, where it still doesn't exist.
2. Coordination between the growth and the improvement of the Indian, Spanish and Italian Green Building Councils is needed.
3. Most European manufacturers are currently unable to supply materials for LEED projects because their products have not been certified according to the US standards. A comparison between the main protocols that regulate the product certifications inside the American and European systems and eventual application limits to the LEED Standard purpose is needed.
4. The "Energy and Atmosphere" chapter contained in the US LEED Manual is the most important for all issues related to building energy performance. An equivalent European management system for these aspects of LEED has not been created yet. Comparison and adjustment of the European standards to American requirements is needed. Implementation of architectural and design solutions concerning screening and shading devices for buildings needs to be

developed in order to meet environmental standards, especially for what concerns the summer-period issues.

The forth of these problems will be addressed by the proposed research.

In this field, because of their nature itself and for the purpose of a research project with a wide range of applicability, the use and implementation of screening and shading devices plays a main role beside other architectural features such as building exposure and use of natural ventilation. The implementation of the last ones can not be extended to some general project conditions because their effect on building performances depends on too many unpredictable variables and therefore such a research project would not result accurate. Climate, wind and exposure characteristics can vary deeply between different zones, even if considering reduced portion of land, whereas shading devices and strategies depend on fewer, predictable and standard features like site latitude, season (sun position) and building orientation.

A research based on shading devices effects would provide more measurable, comparable and therefore accurate results.

B.2 ASHRAE Advanced Energy Design Guide for Small Office Buildings

This standard is strictly connected with the previous document (ASHRAE Standard) and provides a simplified approach for small office buildings. The possibility to follow easy approaches for minor constructions has a big importance given that its applicability would cover a large number of cases. Although this would not be as issue because the cost reduction arising from calculation processes cut down will allow the owners to meet some basic requirement with no extra expenses. The results of this research will have to be applicable to different situations, not only considering the main constructions, but also the minor ones. Therefore is important to have an acknowledgment of the requirement listed under this document which includes:

- Integrated Process to Achieve Energy Savings during the different project stages: Pre-Design Phase, Design Phase, Construction, Acceptance, Occupancy, Maintenance and Other Operation.
- Recommendations by Climate: the choice of the area has to fall upon one of the eight zone-types provided, depending on the project site characteristics.

Improvement of building features through implementation of recommendation: quality assurance, envelope, opaque envelope components, vertical glazing (envelope), window design guidelines for thermal conditions, window design guidelines for daylight, lighting, day lighting, day lighting controls, electric lighting design, HVAC, service water heating, bonus savings, plug loads, exterior lighting.

- Envelope Thermal Performance Factors.

Source: www.ashrae.org (visited on 03/20/2008)

– APPENDIX C –

Single-Space Analysis Results.

C.1 The LEED and USGBC Background

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
0,0,00	1697	1697	130	14932	4376	18326	
4,0,00	1558	1558	120	15272	4476	18388	4596
4,0,12-12	1557	1557	120	15272	4476	18386	4596
4,0,16-16	1557	1557	120	15272	4476	18386	4596
4,0,4-4	1558	1558	120	15272	4476	18388	4596
4,0,8-8	1557	1557	120	15272	4476	18386	4596
4,12,00	1562	1562	120	15213	4458	18337	4578
4,12,12-12	1562	1562	120	15213	4458	18337	4578
4,12,16-16	1562	1562	120	15213	4458	18337	4578
4,12,4-4	1562	1562	120	15213	4458	18337	4578
4,12,8-8	1562	1562	120	15213	4458	18337	4578
4,16,00	1562	1562	120	15213	4458	18337	4578
4,16,12-12	1562	1562	120	15213	4458	18337	4578
4,16,16-16	1562	1562	120	15213	4458	18337	4578
4,16,4-4	1562	1562	120	15213	4458	18337	4578
4,16,8-8	1562	1562	120	15213	4458	18337	4578
4,4,00	1561	1561	120	15224	4462	18346	4582
4,4,12-12	1561	1561	120	15224	4462	18346	4582
4,4,16-16	1561	1561	120	15224	4462	18346	4582
4,4,4-4	1561	1561	120	15224	4462	18346	4582
4,4,8-8	1561	1561	120	15224	4462	18346	4582
4,8,00	1562	1562	120	15213	4458	18337	4578
4,8,12-12	1562	1562	120	15213	4458	18337	4578
4,8,16-16	1562	1562	120	15213	4458	18337	4578
4,8,4-4	1562	1562	120	15213	4458	18337	4578
4,8,8-8	1562	1562	120	15213	4458	18337	4578
8,0,00	1551	1551	119	15415	4518	18517	4637
8,0,12-12	1551	1551	119	15426	4521	18528	4640
8,0,16-16	1551	1551	119	15426	4521	18528	4640
8,0,4-4	1551	1551	119	15426	4521	18528	4640
8,0,8-8	1551	1551	119	15426	4521	18528	4640
8,12,00	1561	1561	120	15219	4460	18341	4580

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
8,12,12-12	1561	1561	120	15219	4460	18341	4580
8,12,16-16	1561	1561	120	15219	4460	18341	4580
8,12,4-4	1561	1561	120	15219	4460	18341	4580
8,12,8-8	1561	1561	120	15219	4460	18341	4580
8,16,00	1562	1562	120	15213	4458	18337	4578
8,16,12-12	1562	1562	120	15213	4458	18337	4578
8,16,16-16	1562	1562	120	15213	4458	18337	4578
8,16,4-4	1562	1562	120	15213	4458	18337	4578
8,16,8-8	1562	1562	120	15213	4458	18337	4578
8,4,00	1556	1556	120	15215	4459	18327	4579
8,4,12-12	1556	1556	120	15245	4468	18357	4588
8,4,16-16	1556	1556	120	15245	4468	18357	4588
8,4,4-4	1556	1556	120	15245	4468	18357	4588
8,4,8-8	1556	1556	120	15245	4468	18357	4588
8,8,00	1559	1559	120	15223	4461	18341	4581
8,8,12-12	1559	1559	120	15223	4461	18341	4581
8,8,16-16	1559	1559	120	15223	4461	18341	4581
8,8,4-4	1559	1559	120	15223	4461	18341	4581
8,8,8-8	1559	1559	120	15223	4461	18341	4581
12,0,00	1544	1544	119	15407	4515	18495	4634
12,0,12-12	1543	1543	119	15422	4520	18508	4639
12,0,16-16	1543	1543	119	15422	4520	18508	4639
12,0,4-4	1543	1543	119	15422	4520	18508	4639
12,0,8-8	1543	1543	119	15422	4520	18508	4639
12,12,00	1558	1558	120	15234	4465	18350	4585
12,12,12-12	1558	1558	120	15241	4467	18357	4587
12,12,16-16	1558	1558	120	15241	4467	18357	4587
12,12,4-4	1558	1558	120	15241	4467	18357	4587
12,12,8-8	1558	1558	120	15241	4467	18357	4587
12,16,00	1559	1559	120	15235	4465	18353	4585
12,16,12-12	1559	1559	120	15235	4465	18353	4585
12,16,16-16	1559	1559	120	15235	4465	18353	4585
12,16,4-4	1559	1559	120	15235	4465	18353	4585
12,16,8-8	1559	1559	120	15235	4465	18353	4585
12,4,00	1549	1549	119	15290	4481	18388	4600

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
12,4,12-12	1549	1549	119	15289	4481	18387	4600
12,4,16-16	1549	1549	119	15289	4481	18387	4600
12,4,4-4	1549	1549	119	15289	4481	18387	4600
12,4,8-8	1549	1549	119	15289	4481	18387	4600
12,8,00	1554	1554	120	15250	4469	18358	4589
12,8,12-12	1554	1554	120	15238	4466	18346	4586
12,8,16-16	1554	1554	120	15238	4466	18346	4586
12,8,4-4	1554	1554	120	15238	4466	18346	4586
12,8,8-8	1554	1554	120	15238	4466	18346	4586
16,0,00	1539	1539	119	15389	4510	18467	4629
16,0,12-12	1538	1538	119	15383	4508	18459	4627
16,0,16-16	1538	1538	119	15383	4508	18459	4627
16,0,4-4	1537	1537	119	15383	4508	18457	4627
16,0,8-8	1538	1538	119	15383	4508	18459	4627
16,12,00	1552	1552	120	15238	4466	18342	4586
16,12,12-12	1551	1551	120	15242	4467	18344	4587
16,12,16-16	1551	1551	120	15242	4467	18344	4587
16,12,4-4	1551	1551	120	15242	4467	18344	4587
16,12,8-8	1551	1551	120	15242	4467	18344	4587
16,16,00	1556	1556	120	15242	4467	18354	4587
16,16,12-12	1556	1556	120	15229	4463	18341	4583
16,16,16-16	1556	1556	120	15229	4463	18341	4583
16,16,4-4	1556	1556	120	15229	4463	18341	4583
16,16,8-8	1556	1556	120	15229	4463	18341	4583
16,4,00	1543	1543	119	15402	4514	18488	4633
16,4,12-12	1542	1542	119	15402	4514	18486	4633
16,4,16-16	1542	1542	119	15402	4514	18486	4633
16,4,4-4	1542	1542	119	15402	4514	18486	4633
16,4,8-8	1542	1542	119	15402	4514	18486	4633
16,8,00	1548	1548	119	15295	4483	18391	4602
16,8,12-12	1547	1547	119	15305	4486	18399	4605
16,8,16-16	1547	1547	119	15305	4486	18399	4605
16,8,4-4	1547	1547	119	15305	4486	18399	4605
16,8,8-8	1547	1547	119	15305	4486	18399	4605
20,0,00	1532	1532	118	15420	4519	18484	4637

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
20,0,12-12	1530	1530	118	15365	4503	18425	4621
20,0,16-16	1530	1530	118	15365	4503	18425	4621
20,0,4-4	1530	1530	118	15374	4506	18434	4624
20,0,8-8	1530	1530	118	15365	4503	18425	4621
20,12,00	1547	1547	119	15291	4481	18385	4600
20,12,12-12	1546	1546	119	15283	4479	18375	4598
20,12,16-16	1546	1546	119	15283	4479	18375	4598
20,12,4-4	1546	1546	119	15273	4476	18365	4595
20,12,8-8	1546	1546	119	15283	4479	18375	4598
20,16,00	1550	1550	119	15251	4470	18351	4589
20,16,12-12	1549	1549	119	15241	4467	18339	4586
20,16,16-16	1549	1549	119	15241	4467	18339	4586
20,16,4-4	1549	1549	119	15239	4466	18337	4585
20,16,8-8	1549	1549	119	15241	4467	18339	4586
20,4,00	1538	1538	119	15394	4512	18470	4631
20,4,12-12	1537	1537	118	15387	4510	18461	4628
20,4,16-16	1537	1537	118	15387	4510	18461	4628
20,4,4-4	1537	1537	118	15403	4514	18477	4632
20,4,8-8	1537	1537	118	15387	4510	18461	4628
20,8,00	1542	1542	119	15331	4493	18415	4612
20,8,12-12	1542	1542	119	15323	4491	18407	4610
20,8,16-16	1542	1542	119	15323	4491	18407	4610
20,8,4-4	1542	1542	119	15312	4487	18396	4606
20,8,8-8	1542	1542	119	15323	4491	18407	4610
24,0,00	1528	1528	118	15371	4505	18427	4623
24,0,12-12	1526	1526	118	15367	4504	18419	4622
24,0,16-16	1526	1526	118	15367	4504	18419	4622
24,0,4-4	1526	1526	118	15388	4510	18440	4628
24,0,8-8	1526	1526	118	15367	4504	18419	4622
24,12,00	1543	1543	119	15321	4490	18407	4609
24,12,12-12	1541	1541	119	15339	4495	18421	4614
24,12,16-16	1541	1541	119	15339	4495	18421	4614
24,12,4-4	1542	1542	119	15300	4484	18384	4603
24,12,8-8	1541	1541	119	15338	4495	18420	4614
24,16,00	1547	1547	119	15252	4470	18346	4589

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
24,16,12-12	1545	1545	119	15268	4475	18358	4594
24,16,16-16	1545	1545	119	15268	4475	18358	4594
24,16,4-4	1546	1546	119	15243	4467	18335	4586
24,16,8-8	1545	1545	119	15265	4474	18355	4593
24,4,00	1532	1532	118	15379	4507	18443	4625
24,4,12-12	1529	1529	118	15337	4495	18395	4613
24,4,16-16	1529	1529	118	15337	4495	18395	4613
24,4,4-4	1530	1530	118	15361	4502	18421	4620
24,4,8-8	1529	1529	118	15337	4495	18395	4613
24,8,00	1538	1538	119	15354	4500	18430	4619
24,8,12-12	1536	1536	118	15362	4502	18434	4620
24,8,16-16	1536	1536	118	15355	4500	18427	4618
24,8,4-4	1536	1536	118	15379	4507	18451	4625
24,8,8-8	1529	1529	118	15337	4495	18395	4613
28,0,00	1523	1523	118	15347	4498	18393	4616
28,0,12-12	1521	1521	117	15317	4489	18359	4606
28,0,16-16	1521	1521	117	15317	4489	18359	4606
28,0,4-4	1522	1522	117	15308	4486	18352	4603
28,0,8-8	1521	1521	117	15336	4494	18378	4611
28,12,00	1538	1538	119	15353	4500	18429	4619
28,12,12-12	1535	1535	118	15326	4492	18396	4610
28,12,16-16	1535	1535	118	15326	4492	18396	4610
28,12,4-4	1536	1536	118	15346	4497	18418	4615
28,12,8-8	1535	1535	118	15337	4495	18407	4613
28,16,00	1542	1542	119	15308	4486	18392	4605
28,16,12-12	1540	1540	119	15291	4481	18371	4600
28,16,16-16	1540	1540	119	15291	4481	18371	4600
28,16,4-4	1541	1541	119	15297	4483	18379	4602
28,16,8-8	1540	1540	119	15286	4480	18366	4599
28,4,00	1529	1529	118	15321	4490	18379	4608
28,4,12-12	1526	1526	118	15375	4506	18427	4624
28,4,16-16	1526	1526	118	15375	4506	18427	4624
28,4,4-4	1527	1527	118	15359	4501	18413	4619
28,4,8-8	1526	1526	118	15370	4505	18422	4623
28,8,00	1532	1532	118	15354	4500	18418	4618

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
28,8,12-12	1530	1530	118	15373	4505	18433	4623
28,8,16-16	1530	1530	118	15373	4505	18433	4623
28,8,4-4	1530	1530	118	15336	4494	18396	4612
28,8,8-8	1530	1530	118	15379	4507	18439	4625
32,0,00	1521	1521	117	15305	4486	18347	4603
32,0,12-12	1518	1518	117	15359	4501	18395	4618
32,0,16-16	1518	1518	117	15356	4500	18392	4617
32,0,4-4	1519	1519	117	15362	4502	18400	4619
32,0,8-8	1519	1519	117	15358	4501	18396	4618
32,12,00	1532	1532	118	15321	4490	18385	4608
32,12,12-12	1529	1529	118	15322	4490	18380	4608
32,12,16-16	1529	1529	118	15322	4490	18380	4608
32,12,4-4	1531	1531	118	15325	4491	18387	4609
32,12,8-8	1530	1530	118	15329	4492	18389	4610
32,16,00	1538	1538	119	15321	4490	18397	4609
32,16,12-12	1535	1535	118	15334	4494	18404	4612
32,16,16-16	1535	1535	118	15314	4488	18384	4606
32,16,4-4	1537	1537	118	15304	4485	18378	4603
32,16,8-8	1535	1535	118	15325	4491	18395	4609
32,4,00	1525	1525	118	15363	4503	18413	4621
32,4,12-12	1522	1522	117	15355	4500	18399	4617
32,4,16-16	1521	1521	117	15334	4494	18376	4611
32,4,4-4	1522	1522	117	15388	4510	18432	4627
32,4,8-8	1521	1521	117	15346	4498	18388	4615
32,8,00	1530	1530	118	15322	4490	18382	4608
32,8,12-12	1526	1526	118	15369	4504	18421	4622
32,8,16-16	1526	1526	118	15367	4504	18419	4622
32,8,4-4	1528	1528	118	15344	4497	18400	4615
32,8,8-8	1527	1527	118	15314	4488	18368	4606
36,0,00	1520	1520	117	15285	4480	18325	4597
36,0,12-12	1515	1515	117	15372	4505	18402	4622
36,0,16-16	1515	1515	117	15376	4506	18406	4623
36,0,4-4	1517	1517	117	15345	4497	18379	4614
36,0,8-8	1515	1515	117	15350	4499	18380	4616
36,12,00	1531	1531	118	15318	4489	18380	4607

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
36,12,12-12	1526	1526	118	15354	4500	18406	4618
36,12,16-16	1527	1527	118	15364	4503	18418	4621
36,12,4-4	1528	1528	118	15343	4497	18399	4615
36,12,8-8	1527	1527	118	15350	4499	18404	4617
36,16,00	1534	1534	118	15312	4488	18380	4606
36,16,12-12	1530	1530	118	15306	4486	18366	4604
36,16,16-16	1530	1530	118	15306	4486	18366	4604
36,16,4-4	1532	1532	118	15326	4492	18390	4610
36,16,8-8	1531	1531	118	15319	4490	18381	4608
36,4,00	1522	1522	117	15382	4508	18426	4625
36,4,12-12	1519	1519	117	15392	4511	18430	4628
36,4,16-16	1518	1518	117	15380	4507	18416	4624
36,4,4-4	1520	1520	117	15366	4503	18406	4620
36,4,8-8	1519	1519	117	15375	4506	18413	4623
36,8,00	1526	1526	118	15372	4505	18424	4623
36,8,12-12	1522	1522	117	15363	4503	18407	4620
36,8,16-16	1522	1522	117	15372	4505	18416	4622
36,8,4-4	1524	1524	118	15364	4503	18412	4621
36,8,8-8	1521	1521	117	15348	4498	18390	4615
40,0,00	1518	1518	117	15346	4497	18382	4614
40,0,12-12	1513	1513	117	15354	4500	18380	4617
40,0,16-16	1512	1512	117	15341	4496	18365	4613
40,0,4-4	1515	1515	117	15366	4503	18396	4620
40,0,8-8	1514	1514	117	15361	4502	18389	4619
40,12,00	1528	1528	118	15325	4491	18381	4609
40,12,12-12	1522	1522	117	15312	4488	18356	4605
40,12,16-16	1523	1523	117	15328	4492	18374	4609
40,12,4-4	1525	1525	118	15348	4498	18398	4616
40,12,8-8	1524	1524	118	15341	4496	18389	4614
40,16,00	1531	1531	118	15316	4489	18378	4607
40,16,12-12	1527	1527	118	15328	4492	18382	4610
40,16,16-16	1526	1526	118	15346	4498	18398	4616
40,16,4-4	1529	1529	118	15337	4495	18395	4613
40,16,8-8	1528	1528	118	15357	4501	18413	4619
40,4,00	1521	1521	117	15380	4507	18422	4624

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
40,4,12-12	1516	1516	117	15342	4496	18374	4613
40,4,16-16	1515	1515	117	15339	4496	18369	4613
40,4,4-4	1518	1518	117	15389	4510	18425	4627
40,4,8-8	1516	1516	117	15356	4501	18388	4618
40,8,00	1523	1523	117	15387	4509	18433	4626
40,8,12-12	1519	1519	117	15392	4511	18430	4628
40,8,16-16	1518	1518	117	15347	4498	18383	4615
40,8,4-4	1521	1521	117	15356	4500	18398	4617
40,8,8-8	1518	1518	117	15378	4507	18414	4624
44,0,00	1516	1516	117	15357	4501	18389	4618
44,0,12-12	1511	1511	117	15405	4515	18427	4632
44,0,16-16	1510	1510	117	15399	4513	18419	4630
44,0,4-4	1514	1514	117	15362	4502	18390	4619
44,0,8-8	1512	1512	117	15382	4508	18406	4625
44,12,00	1526	1526	118	15332	4493	18384	4611
44,12,12-12	1519	1519	117	15374	4506	18412	4623
44,12,16-16	1520	1520	117	15334	4494	18374	4611
44,12,4-4	1523	1523	117	15367	4504	18413	4621
44,12,8-8	1520	1520	117	15409	4516	18449	4633
44,16,00	1529	1529	118	15269	4475	18327	4593
44,16,12-12	1523	1523	117	15319	4490	18365	4607
44,16,16-16	1522	1522	117	15343	4496	18387	4613
44,16,4-4	1527	1527	118	15320	4490	18374	4608
44,16,8-8	1525	1525	118	15332	4493	18382	4611
44,4,00	1519	1519	117	15378	4507	18416	4624
44,4,12-12	1513	1513	117	15414	4517	18440	4634
44,4,16-16	1513	1513	117	15388	4510	18414	4627
44,4,4-4	1517	1517	117	15309	4486	18343	4603
44,4,8-8	1515	1515	117	15392	4511	18422	4628
44,8,00	1522	1522	117	15392	4511	18436	4628
44,8,12-12	1516	1516	117	15374	4506	18406	4623
44,8,16-16	1516	1516	117	15382	4508	18414	4625
44,8,4-4	1518	1518	117	15419	4519	18455	4636
44,8,8-8	1517	1517	117	15346	4497	18380	4614
48,0,00	1515	1515	117	15373	4505	18403	4622

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
48,0,12-12	1510	1510	117	15458	4530	18478	4647
48,0,16-16	1508	1508	116	15481	4537	18497	4653
48,0,4-4	1513	1513	117	15412	4517	18438	4634
48,0,8-8	1511	1511	117	15461	4531	18483	4648
48,12,00	1524	1524	118	15380	4507	18428	4625
48,12,12-12	1517	1517	117	15398	4513	18432	4630
48,12,16-16	1516	1516	117	15415	4518	18447	4635
48,12,4-4	1520	1520	117	15394	4511	18434	4628
48,12,8-8	1518	1518	117	15401	4513	18437	4630
48,16,00	1527	1527	118	15315	4488	18369	4606
48,16,12-12	1520	1520	117	15301	4484	18341	4601
48,16,16-16	1519	1519	117	15312	4487	18350	4604
48,16,4-4	1524	1524	118	15303	4485	18351	4603
48,16,8-8	1521	1521	117	15289	4481	18331	4598
48,4,00	1518	1518	117	15364	4503	18400	4620
48,4,12-12	1512	1512	117	15435	4524	18459	4641
48,4,16-16	1511	1511	117	15408	4516	18430	4633
48,4,4-4	1515	1515	117	15372	4505	18402	4622
48,4,8-8	1513	1513	117	15406	4515	18432	4632
48,8,00	1520	1520	117	15383	4508	18423	4625
48,8,12-12	1514	1514	117	15388	4510	18416	4627
48,8,16-16	1514	1514	117	15383	4508	18411	4625
48,8,4-4	1518	1518	117	15373	4505	18409	4622
48,8,8-8	1516	1516	117	15412	4517	18444	4634
52,0,00	1515	1515	117	15357	4501	18387	4618
52,0,12-12	1509	1509	116	15463	4532	18481	4648
52,0,16-16	1507	1507	116	15476	4535	18490	4651
52,0,4-4	1512	1512	117	15463	4532	18487	4649
52,0,8-8	1510	1510	117	15465	4532	18485	4649
52,12,00	1522	1522	117	15422	4520	18466	4637
52,12,12-12	1515	1515	117	15394	4511	18424	4628
52,12,16-16	1514	1514	117	15441	4525	18469	4642
52,12,4-4	1522	1522	117	15422	4520	18466	4637
52,12,8-8	1517	1517	117	15354	4500	18388	4617
52,16,00	1526	1526	118	15349	4498	18401	4616

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
52,16,12-12	1518	1518	117	15387	4509	18423	4626
52,16,16-16	1517	1517	117	15379	4507	18413	4624
52,16,4-4	1520	1520	117	15399	4513	18439	4630
52,16,8-8	1519	1519	117	15386	4509	18424	4626
52,4,00	1518	1518	117	15361	4502	18397	4619
52,4,12-12	1510	1510	117	15435	4524	18455	4641
52,4,16-16	1510	1510	117	15422	4520	18442	4637
52,4,4-4	1514	1514	117	15395	4512	18423	4629
52,4,8-8	1512	1512	117	15393	4511	18417	4628
52,8,00	1520	1520	117	15387	4509	18427	4626
52,8,12-12	1512	1512	117	15404	4514	18428	4631
52,8,16-16	1512	1512	117	15423	4520	18447	4637
52,8,4-4	1517	1517	117	15347	4498	18381	4615
52,8,8-8	1515	1515	117	15346	4497	18376	4614
56,0,00	1514	1514	117	15426	4521	18454	4638
56,0,12-12	1508	1508	116	15485	4538	18501	4654
56,0,16-16	1507	1507	116	15485	4538	18499	4654
56,0,4-4	1512	1512	117	15501	4543	18525	4660
56,0,8-8	1510	1510	117	15484	4538	18504	4655
56,12,00	1522	1522	117	15377	4506	18421	4623
56,12,12-12	1514	1514	117	15430	4522	18458	4639
56,12,16-16	1513	1513	117	15389	4510	18415	4627
56,12,4-4	1518	1518	117	15396	4512	18432	4629
56,12,8-8	1516	1516	117	15405	4515	18437	4632
56,16,00	1523	1523	118	15340	4496	18386	4614
56,16,12-12	1516	1516	117	15442	4526	18474	4643
56,16,16-16	1515	1515	117	15398	4513	18428	4630
56,16,4-4	1520	1520	117	15399	4513	18439	4630
56,16,8-8	1518	1518	117	15403	4514	18439	4631
56,4,00	1517	1517	117	15370	4504	18404	4621
56,4,12-12	1510	1510	117	15469	4533	18489	4650
56,4,16-16	1508	1508	116	15485	4538	18501	4654
56,4,4-4	1513	1513	117	15404	4515	18430	4632
56,4,8-8	1511	1511	117	15427	4521	18449	4638
56,8,00	1520	1520	117	15369	4504	18409	4621

1 WINDOW OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cool. Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
56,8,12-12	1512	1512	117	15400	4513	18424	4630
56,8,16-16	1511	1511	117	15409	4516	18431	4633
56,8,4-4	1517	1517	117	15348	4498	18382	4615
56,8,8-8	1514	1514	117	15378	4507	18406	4624
60,0,00	1514	1514	117	15459	4531	18487	4648
60,0,12-12	1507	1507	116	15504	4544	18518	4660
60,0,16-16	1506	1506	116	15495	4541	18507	4657
60,0,4-4	1511	1511	117	15504	4544	18526	4661
60,0,8-8	1510	1510	117	15496	4541	18516	4658
60,12,00	1521	1521	117	15412	4517	18454	4634
60,12,12-12	1513	1513	117	15420	4519	18446	4636
60,12,16-16	1512	1512	117	15417	4518	18441	4635
60,12,4-4	1518	1518	117	15420	4519	18456	4636
60,12,8-8	1516	1516	117	15367	4504	18399	4621
60,16,00	1523	1523	117	15372	4505	18418	4622
60,16,12-12	1515	1515	117	15409	4516	18439	4633
60,16,16-16	1514	1514	117	15416	4518	18444	4635
60,16,4-4	1519	1519	117	15417	4518	18455	4635
60,16,8-8	1517	1517	117	15410	4516	18444	4633
60,4,00	1517	1517	117	15332	4493	18366	4610
60,4,12-12	1510	1510	117	15487	4539	18507	4656
60,4,16-16	1508	1508	116	15461	4531	18477	4647
60,4,4-4	1513	1513	117	15426	4521	18452	4638
60,4,8-8	1511	1511	117	15501	4543	18523	4660
60,8,00	1519	1519	117	15341	4496	18379	4613
60,8,12-12	1511	1511	117	15414	4517	18436	4634
60,8,16-16	1510	1510	117	15458	4530	18478	4647
60,8,4-4	1516	1516	117	15376	4506	18408	4623
60,8,8-8	1513	1513	117	15433	4523	18459	4640
					MINIMUM	18325	
					MAX	18528	

C.2 Single-Space Analysis B Results.

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
0,0,00	2120	2120	161	14785	4333	19025	4494
4,0,00	1840	1840	140	15081	4420	18761	4560
4,0,12-12	1840	1840	140	15081	4420	18761	4560
4,0,16-16	1840	1840	140	15081	4420	18761	4560
4,0,4-4	1840	1840	140	15081	4420	18761	4560
4,0,8-8	1840	1840	140	15081	4420	18761	4560
4,12,00	1852	1852	141	15032	4406	18736	4547
4,12,12-12	1852	1852	141	15032	4406	18736	4547
4,12,16-16	1852	1852	141	15032	4406	18736	4547
4,12,4-4	1852	1852	141	15032	4406	18736	4547
4,12,8-8	1852	1852	141	15032	4406	18736	4547
4,16,00	1852	1852	141	15032	4406	18736	4547
4,16,12-12	1852	1852	141	15032	4406	18736	4547
4,16,16-16	1852	1852	141	15032	4406	18736	4547
4,16,4-4	1852	1852	141	15032	4406	18736	4547
4,16,8-8	1852	1852	141	15032	4406	18736	4547
4,4,00	1848	1848	141	15036	4407	18732	4548
4,4,12-12	1848	1848	141	15036	4407	18732	4548
4,4,16-16	1848	1848	141	15036	4407	18732	4548
4,4,4-4	1848	1848	141	15036	4407	18732	4548
4,4,8-8	1848	1848	141	15036	4407	18732	4548
4,8,00	1852	1852	141	15032	4406	18736	4547
4,8,12-12	1852	1852	141	15032	4406	18736	4547
4,8,16-16	1852	1852	141	15032	4406	18736	4547
4,8,4-4	1852	1852	141	15032	4406	18736	4547
4,8,8-8	1852	1852	141	15032	4406	18736	4547
8,0,00	1821	1821	139	15055	4412	18697	4551
8,0,12-12	1821	1821	139	15051	4411	18693	4550
8,0,16-16	1821	1821	139	15051	4411	18693	4550
8,0,4-4	1821	1821	139	15051	4411	18693	4550
8,0,8-8	1821	1821	139	15051	4411	18693	4550
8,12,00	1850	1850	141	15045	4409	18745	4550

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
8,12,12-12	1850	1850	141	15045	4409	18745	4550
8,12,16-16	1850	1850	141	15045	4409	18745	4550
8,12,4-4	1850	1850	141	15045	4409	18745	4550
8,12,8-8	1850	1850	141	15045	4409	18745	4550
8,16,00	1852	1852	141	15032	4406	18736	4547
8,16,12-12	1852	1852	141	15032	4406	18736	4547
8,16,16-16	1852	1852	141	15032	4406	18736	4547
8,16,4-4	1852	1852	141	15032	4406	18736	4547
8,16,8-8	1852	1852	141	15032	4406	18736	4547
8,4,00	1833	1833	140	15073	4417	18739	4557
8,4,12-12	1833	1833	140	15073	4417	18739	4557
8,4,16-16	1833	1833	140	15073	4417	18739	4557
8,4,4-4	1833	1833	140	15073	4417	18739	4557
8,4,8-8	1833	1833	140	15073	4417	18739	4557
8,8,00	1844	1844	141	15062	4414	18750	4555
8,8,12-12	1844	1844	141	15062	4414	18750	4555
8,8,16-16	1844	1844	141	15062	4414	18750	4555
8,8,4-4	1844	1844	141	15062	4414	18750	4555
8,8,8-8	1844	1844	141	15062	4414	18750	4555
12,0,00	1805	1805	138	15046	4410	18656	4548
12,0,12-12	1804	1804	138	15033	4406	18641	4544
12,0,16-16	1804	1804	138	15033	4406	18641	4544
12,0,4-4	1804	1804	138	15033	4406	18641	4544
12,0,8-8	1804	1804	138	15033	4406	18641	4544
12,12,00	1838	1838	140	15057	4413	18733	4553
12,12,12-12	1838	1838	140	15057	4413	18733	4553
12,12,16-16	1838	1838	140	15057	4413	18733	4553
12,12,4-4	1838	1838	140	15057	4413	18733	4553
12,12,8-8	1838	1838	140	15057	4413	18733	4553
12,16,00	1844	1844	141	15051	4411	18739	4552
12,16,12-12	1844	1844	141	15052	4411	18740	4552
12,16,16-16	1844	1844	141	15052	4411	18740	4552
12,16,4-4	1844	1844	141	15052	4411	18740	4552
12,16,8-8	1844	1844	141	15052	4411	18740	4552
12,4,00	1818	1818	139	15039	4407	18675	4546

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
12,4,12-12	1818	1818	139	15046	4409	18682	4548
12,4,16-16	1818	1818	139	15046	4409	18682	4548
12,4,4-4	1818	1818	139	15046	4409	18682	4548
12,4,8-8	1818	1818	139	15046	4409	18682	4548
12,8,00	1828	1828	140	15043	4409	18699	4549
12,8,12-12	1828	1828	140	15044	4409	18700	4549
12,8,16-16	1828	1828	140	15044	4409	18700	4549
12,8,4-4	1828	1828	140	15044	4409	18700	4549
12,8,8-8	1828	1828	140	15044	4409	18700	4549
16,0,00	1790	1790	137	15054	4412	18634	4549
16,0,12-12	1789	1789	137	15066	4415	18644	4552
16,0,16-16	1789	1789	137	15066	4415	18644	4552
16,0,4-4	1789	1789	137	15066	4415	18644	4552
16,0,8-8	1789	1789	137	15066	4415	18644	4552
16,12,00	1824	1824	139	15069	4416	18717	4555
16,12,12-12	1824	1824	139	15077	4419	18725	4558
16,12,16-16	1824	1824	139	15077	4419	18725	4558
16,12,4-4	1824	1824	139	15077	4419	18725	4558
16,12,8-8	1824	1824	139	15077	4419	18725	4558
16,16,00	1833	1833	140	15078	4419	18744	4559
16,16,12-12	1832	1832	140	15078	4419	18742	4559
16,16,16-16	1832	1832	140	15078	4419	18742	4559
16,16,4-4	1832	1832	140	15078	4419	18742	4559
16,16,8-8	1832	1832	140	15078	4419	18742	4559
16,4,00	1802	1802	138	15010	4399	18614	4537
16,4,12-12	1802	1802	138	15008	4398	18612	4536
16,4,16-16	1802	1802	138	15008	4398	18612	4536
16,4,4-4	1802	1802	138	15008	4398	18612	4536
16,4,8-8	1802	1802	138	15008	4398	18612	4536
16,8,00	1816	1816	139	15079	4419	18711	4558
16,8,12-12	1815	1815	139	15070	4417	18700	4556
16,8,16-16	1815	1815	139	15070	4417	18700	4556
16,8,4-4	1815	1815	139	15070	4417	18700	4556
16,8,8-8	1815	1815	139	15070	4417	18700	4556
20,0,00	1774	1774	136	15011	4399	18559	4535

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
20,0,12-12	1773	1773	136	15018	4401	18564	4537
20,0,16-16	1773	1773	136	15018	4401	18564	4537
20,0,4-4	1773	1773	136	15029	4405	18575	4541
20,0,8-8	1773	1773	136	15018	4401	18564	4537
20,12,00	1812	1812	138	15043	4409	18667	4547
20,12,12-12	1812	1812	138	15039	4407	18663	4545
20,12,16-16	1812	1812	138	15039	4407	18663	4545
20,12,4-4	1812	1812	138	15040	4408	18664	4546
20,12,8-8	1812	1812	138	15039	4407	18663	4545
20,16,00	1822	1822	139	15060	4414	18704	4553
20,16,12-12	1821	1821	139	15065	4415	18707	4554
20,16,16-16	1821	1821	139	15065	4415	18707	4554
20,16,4-4	1821	1821	139	15064	4415	18706	4554
20,16,8-8	1821	1821	139	15065	4415	18707	4554
20,4,00	1789	1789	137	15035	4406	18613	4543
20,4,12-12	1787	1787	137	15026	4404	18600	4541
20,4,16-16	1787	1787	137	15026	4404	18600	4541
20,4,4-4	1787	1787	137	15027	4404	18601	4541
20,4,8-8	1787	1787	137	15026	4404	18600	4541
20,8,00	1800	1800	138	15018	4401	18618	4539
20,8,12-12	1798	1798	137	14994	4394	18590	4531
20,8,16-16	1798	1798	137	14994	4394	18590	4531
20,8,4-4	1799	1799	138	14996	4395	18594	4533
20,8,8-8	1798	1798	137	14994	4394	18590	4531
24,0,00	1765	1765	135	15135	4436	18665	4571
24,0,12-12	1762	1762	135	15117	4430	18641	4565
24,0,16-16	1762	1762	135	15117	4430	18641	4565
24,0,4-4	1763	1763	135	15128	4434	18654	4569
24,0,8-8	1762	1762	135	15117	4430	18641	4565
24,12,00	1800	1800	138	14993	4394	18593	4532
24,12,12-12	1797	1797	137	14988	4393	18582	4530
24,12,16-16	1797	1797	137	14988	4393	18582	4530
24,12,4-4	1798	1798	137	14985	4392	18581	4529
24,12,8-8	1797	1797	137	14988	4393	18582	4530
24,16,00	1811	1811	138	15026	4404	18648	4542

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
24,16,12-12	1809	1809	138	15018	4401	18636	4539
24,16,16-16	1809	1809	138	15018	4401	18636	4539
24,16,4-4	1810	1810	138	15020	4402	18640	4540
24,16,8-8	1809	1809	138	15018	4401	18636	4539
24,4,00	1775	1775	136	15030	4405	18580	4541
24,4,12-12	1772	1772	136	15041	4408	18585	4544
24,4,16-16	1772	1772	136	15041	4408	18585	4544
24,4,4-4	1773	1773	136	15013	4400	18559	4536
24,4,8-8	1772	1772	136	15019	4402	18563	4538
24,8,00	1788	1788	137	15028	4404	18604	4541
24,8,12-12	1786	1786	137	15029	4405	18601	4542
24,8,16-16	1786	1786	137	15027	4404	18599	4541
24,8,4-4	1787	1787	137	15042	4408	18616	4545
24,8,8-8	1772	1772	136	15019	4402	18563	4538
28,0,00	1753	1753	134	15181	4449	18687	4583
28,0,12-12	1750	1750	134	15231	4464	18731	4598
28,0,16-16	1750	1750	134	15240	4466	18740	4600
28,0,4-4	1751	1751	134	15261	4473	18763	4607
28,0,8-8	1750	1750	134	15235	4465	18735	4599
28,12,00	1786	1786	137	14989	4393	18561	4530
28,12,12-12	1784	1784	136	15011	4399	18579	4535
28,12,16-16	1784	1784	136	15011	4399	18579	4535
28,12,4-4	1785	1785	137	15014	4400	18584	4537
28,12,8-8	1785	1785	136	14998	4396	18568	4532
28,16,00	1798	1798	137	14979	4390	18575	4527
28,16,12-12	1796	1796	137	14983	4391	18575	4528
28,16,16-16	1796	1796	137	14983	4391	18575	4528
28,16,4-4	1797	1797	137	15004	4397	18598	4534
28,16,8-8	1796	1796	137	14983	4391	18575	4528
28,4,00	1766	1766	135	15039	4407	18571	4542
28,4,12-12	1761	1761	135	15032	4405	18554	4540
28,4,16-16	1761	1761	135	15032	4405	18554	4540
28,4,4-4	1763	1763	135	15030	4405	18556	4540
28,4,8-8	1762	1762	135	15032	4405	18556	4540
28,8,00	1775	1775	136	15084	4421	18634	4557

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
28,8,12-12	1772	1772	136	15042	4408	18586	4544
28,8,16-16	1772	1772	136	15042	4408	18586	4544
28,8,4-4	1773	1773	136	15045	4409	18591	4545
28,8,8-8	1773	1773	136	15042	4408	18588	4544
32,0,00	1744	1744	134	15258	4472	18746	4606
32,0,12-12	1740	1740	133	15278	4478	18758	4611
32,0,16-16	1739	1739	133	15279	4478	18757	4611
32,0,4-4	1742	1742	133	15243	4467	18727	4600
32,0,8-8	1740	1740	133	15257	4471	18737	4604
32,12,00	1774	1774	136	15058	4413	18606	4549
32,12,12-12	1771	1771	136	15044	4409	18586	4545
32,12,16-16	1771	1771	136	15039	4407	18581	4543
32,12,4-4	1772	1772	136	15031	4405	18575	4541
32,12,8-8	1772	1772	136	15029	4405	18573	4541
32,16,00	1785	1785	137	14966	4386	18536	4523
32,16,12-12	1783	1783	136	15005	4398	18571	4534
32,16,16-16	1782	1782	136	15005	4398	18569	4534
32,16,4-4	1784	1784	136	14999	4396	18567	4532
32,16,8-8	1783	1783	136	15002	4397	18568	4533
32,4,00	1754	1754	134	15169	4446	18677	4580
32,4,12-12	1749	1749	134	15148	4439	18646	4573
32,4,16-16	1749	1749	134	15144	4438	18642	4572
32,4,4-4	1752	1752	134	15152	4441	18656	4575
32,4,8-8	1750	1750	134	15127	4433	18627	4567
32,8,00	1766	1766	135	15041	4408	18573	4543
32,8,12-12	1761	1761	135	15031	4405	18553	4540
32,8,16-16	1761	1761	135	15062	4414	18584	4549
32,8,4-4	1764	1764	135	15020	4402	18548	4537
32,8,8-8	1762	1762	135	15020	4402	18544	4537
36,0,00	1738	1738	133	15311	4487	18787	4620
36,0,12-12	1732	1732	133	15353	4499	18817	4632
36,0,16-16	1732	1732	133	15334	4494	18798	4627
36,0,4-4	1735	1735	133	15313	4488	18783	4621
36,0,8-8	1733	1733	133	15319	4489	18785	4622
36,12,00	1767	1767	135	15046	4410	18580	4545

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
36,12,12-12	1762	1762	135	15060	4414	18584	4549
36,12,16-16	1761	1761	135	15065	4415	18587	4550
36,12,4-4	1765	1765	135	15040	4408	18570	4543
36,12,8-8	1763	1763	135	15041	4408	18567	4543
36,16,00	1775	1775	136	15053	4411	18603	4547
36,16,12-12	1770	1770	135	15072	4417	18612	4552
36,16,16-16	1770	1770	135	15084	4421	18624	4556
36,16,4-4	1773	1773	136	15057	4413	18603	4549
36,16,8-8	1771	1771	136	15074	4418	18616	4554
36,4,00	1747	1747	134	15185	4450	18679	4584
36,4,12-12	1740	1740	133	15176	4448	18656	4581
36,4,16-16	1740	1740	133	15184	4450	18664	4583
36,4,4-4	1744	1744	134	15162	4444	18650	4578
36,4,8-8	1742	1742	133	15167	4445	18651	4578
36,8,00	1756	1756	134	15116	4430	18628	4564
36,8,12-12	1751	1751	134	15110	4428	18612	4562
36,8,16-16	1750	1750	134	15138	4436	18638	4570
36,8,4-4	1753	1753	134	15136	4436	18642	4570
36,8,8-8	1752	1752	134	15158	4443	18662	4577
40,0,00	1730	1730	133	15369	4504	18829	4637
40,0,12-12	1723	1723	132	15403	4514	18849	4646
40,0,16-16	1723	1723	132	15403	4514	18849	4646
40,0,4-4	1728	1728	132	15339	4495	18795	4627
40,0,8-8	1724	1724	132	15377	4506	18825	4638
40,12,00	1759	1759	135	15065	4415	18583	4550
40,12,12-12	1752	1752	134	15130	4434	18634	4568
40,12,16-16	1751	1751	134	15149	4440	18651	4574
40,12,4-4	1756	1756	134	15088	4422	18600	4556
40,12,8-8	1753	1753	134	15144	4438	18650	4572
40,16,00	1769	1769	135	15015	4401	18553	4536
40,16,12-12	1763	1763	135	15031	4405	18557	4540
40,16,16-16	1761	1761	135	15028	4404	18550	4539
40,16,4-4	1765	1765	135	15007	4398	18537	4533
40,16,8-8	1764	1764	135	15028	4404	18556	4539
40,4,00	1740	1740	133	15284	4479	18764	4612

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
40,4,12-12	1734	1734	133	15291	4481	18759	4614
40,4,16-16	1733	1733	133	15328	4492	18794	4625
40,4,4-4	1737	1737	133	15261	4473	18735	4606
40,4,8-8	1735	1735	133	15300	4484	18770	4617
40,8,00	1749	1749	134	15168	4445	18666	4579
40,8,12-12	1743	1743	134	15196	4453	18682	4587
40,8,16-16	1741	1741	133	15198	4454	18680	4587
40,8,4-4	1746	1746	134	15165	4444	18657	4578
40,8,8-8	1745	1745	134	15174	4447	18664	4581
44,0,00	1723	1723	132	15402	4514	18848	4646
44,0,12-12	1715	1715	132	15434	4523	18864	4655
44,0,16-16	1715	1715	132	15438	4524	18868	4656
44,0,4-4	1720	1720	132	15420	4519	18860	4651
44,0,8-8	1716	1716	132	15373	4505	18805	4637
44,12,00	1751	1751	134	15150	4440	18652	4574
44,12,12-12	1745	1745	134	15163	4444	18653	4578
44,12,16-16	1743	1743	133	15165	4444	18651	4577
44,12,4-4	1748	1748	134	15120	4431	18616	4565
44,12,8-8	1745	1745	134	15143	4438	18633	4572
44,16,00	1760	1760	135	15080	4420	18600	4555
44,16,12-12	1753	1753	134	15123	4432	18629	4566
44,16,16-16	1752	1752	134	15141	4438	18645	4572
44,16,4-4	1757	1757	135	15086	4421	18600	4556
44,16,8-8	1754	1754	134	15128	4434	18636	4568
44,4,00	1734	1734	133	15316	4489	18784	4622
44,4,12-12	1726	1726	132	15353	4500	18805	4632
44,4,16-16	1725	1725	132	15355	4500	18805	4632
44,4,4-4	1731	1731	133	15290	4481	18752	4614
44,4,8-8	1728	1728	132	15317	4489	18773	4621
44,8,00	1743	1743	134	15222	4461	18708	4595
44,8,12-12	1736	1736	133	15226	4462	18698	4595
44,8,16-16	1734	1734	133	15257	4471	18725	4604
44,8,4-4	1739	1739	133	15239	4466	18717	4599
44,8,8-8	1737	1737	133	15240	4466	18714	4599
48,0,00	1718	1718	132	15409	4516	18845	4648

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
48,0,12-12	1710	1710	131	15459	4531	18879	4662
48,0,16-16	1709	1709	131	15448	4527	18866	4658
48,0,4-4	1714	1714	132	15436	4524	18864	4656
48,0,8-8	1711	1711	131	15444	4526	18866	4657
48,12,00	1744	1744	134	15235	4465	18723	4599
48,12,12-12	1737	1737	133	15240	4466	18714	4599
48,12,16-16	1736	1736	133	15230	4463	18702	4596
48,12,4-4	1742	1742	133	15217	4460	18701	4593
48,12,8-8	1738	1738	133	15227	4463	18703	4596
48,16,00	1753	1753	134	15167	4445	18673	4579
48,16,12-12	1745	1745	134	15123	4432	18613	4566
48,16,16-16	1744	1744	134	15099	4425	18587	4559
48,16,4-4	1750	1750	134	15167	4445	18667	4579
48,16,8-8	1747	1747	134	15133	4435	18627	4569
48,4,00	1728	1728	133	15361	4502	18817	4635
48,4,12-12	1719	1719	132	15476	4536	18914	4668
48,4,16-16	1718	1718	132	15395	4512	18831	4644
48,4,4-4	1724	1724	132	15377	4507	18825	4639
48,4,8-8	1721	1721	132	15414	4517	18856	4649
48,8,00	1737	1737	133	15300	4484	18774	4617
48,8,12-12	1728	1728	132	15331	4493	18787	4625
48,8,16-16	1727	1727	132	15332	4493	18786	4625
48,8,4-4	1733	1733	133	15261	4472	18727	4605
48,8,8-8	1731	1731	133	15318	4489	18780	4622
52,0,00	1714	1714	131	15454	4529	18882	4660
52,0,12-12	1707	1707	131	15480	4537	18894	4668
52,0,16-16	1706	1706	131	15453	4529	18865	4660
52,0,4-4	1710	1710	131	15484	4538	18904	4669
52,0,8-8	1708	1708	131	15459	4531	18875	4662
52,12,00	1739	1739	133	15220	4461	18698	4594
52,12,12-12	1730	1730	133	15285	4480	18745	4613
52,12,16-16	1729	1729	133	15279	4478	18737	4611
52,12,4-4	1739	1739	133	15220	4461	18698	4594
52,12,8-8	1732	1732	133	15305	4485	18769	4618
52,16,00	1748	1748	134	15196	4454	18692	4588

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
52,16,12-12	1739	1739	133	15235	4465	18713	4598
52,16,16-16	1738	1738	133	15249	4469	18725	4602
52,16,4-4	1738	1738	133	15183	4450	18659	4583
52,16,8-8	1742	1742	133	15200	4455	18684	4588
52,4,00	1722	1722	132	15376	4506	18820	4638
52,4,12-12	1712	1712	131	15468	4533	18892	4664
52,4,16-16	1711	1711	131	15449	4528	18871	4659
52,4,4-4	1717	1717	132	15386	4509	18820	4641
52,4,8-8	1715	1715	132	15371	4505	18801	4637
52,8,00	1732	1732	133	15304	4485	18768	4618
52,8,12-12	1723	1723	132	15363	4502	18809	4634
52,8,16-16	1721	1721	132	15391	4511	18833	4643
52,8,4-4	1728	1728	132	15329	4493	18785	4625
52,8,8-8	1725	1725	132	15353	4500	18803	4632
56,0,00	1711	1711	131	15443	4526	18865	4657
56,0,12-12	1704	1704	131	15402	4514	18810	4645
56,0,16-16	1704	1704	131	15415	4518	18823	4649
56,0,4-4	1708	1708	131	15439	4525	18855	4656
56,0,8-8	1705	1705	131	15436	4524	18846	4655
56,12,00	1735	1735	133	15284	4479	18754	4612
56,12,12-12	1725	1725	132	15354	4500	18804	4632
56,12,16-16	1723	1723	132	15318	4489	18764	4621
56,12,4-4	1731	1731	133	15296	4483	18758	4616
56,12,8-8	1727	1727	132	15304	4485	18758	4617
56,16,00	1742	1742	133	15207	4457	18691	4590
56,16,12-12	1733	1733	133	15293	4482	18759	4615
56,16,16-16	1731	1731	133	15316	4489	18778	4622
56,16,4-4	1738	1738	133	15183	4450	18659	4583
56,16,8-8	1735	1735	133	15212	4458	18682	4591
56,4,00	1718	1718	132	15462	4532	18898	4664
56,4,12-12	1708	1708	131	15473	4535	18889	4666
56,4,16-16	1707	1707	131	15502	4543	18916	4674
56,4,4-4	1713	1713	131	15517	4548	18943	4679
56,4,8-8	1711	1711	131	15486	4539	18908	4670
56,8,00	1726	1726	132	15385	4509	18837	4641

2 WINDOWS OF 5 BY 6 FEET							
Depth, height, edges	Central Cooling Coil Load	Central Cooling Eqpt. Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
56,8,12-12	1715	1715	132	15444	4526	18874	4658
56,8,16-16	1713	1713	131	15391	4511	18817	4642
56,8,4-4	1721	1721	132	15389	4510	18831	4642
56,8,8-8	1716	1716	132	15443	4526	18875	4658
60,0,00	1710	1710	131	15408	4516	18828	4647
60,0,12-12	1702	1702	131	15447	4527	18851	4658
60,0,16-16	1701	1701	131	15421	4519	18823	4650
60,0,4-4	1706	1706	131	15414	4517	18826	4648
60,0,8-8	1703	1703	131	15385	4509	18791	4640
60,12,00	1730	1730	133	15294	4482	18754	4615
60,12,12-12	1717	1717	132	15384	4509	18818	4641
60,12,16-16	1715	1715	132	15416	4518	18846	4650
60,12,4-4	1725	1725	132	15335	4494	18785	4626
60,12,8-8	1721	1721	132	15366	4503	18808	4635
60,16,00	1736	1736	133	15282	4479	18754	4612
60,16,12-12	1726	1726	132	15342	4496	18794	4628
60,16,16-16	1725	1725	132	15303	4485	18753	4617
60,16,4-4	1733	1733	133	15270	4475	18736	4608
60,16,8-8	1730	1730	133	15351	4499	18811	4632
60,4,00	1714	1714	131	15432	4523	18860	4654
60,4,12-12	1706	1706	131	15433	4523	18845	4654
60,4,16-16	1705	1705	131	15448	4527	18858	4658
60,4,4-4	1710	1710	131	15456	4530	18876	4661
60,4,8-8	1708	1708	131	15469	4533	18885	4664
60,8,00	1722	1722	132	15409	4516	18853	4648
60,8,12-12	1711	1711	131	15462	4531	18884	4662
60,8,16-16	1710	1710	131	15447	4527	18867	4658
60,8,4-4	1717	1717	132	15435	4523	18869	4655
60,8,8-8	1713	1713	131	15427	4521	18853	4652
					MIN	18536	
					MAX	19025	

C.3 Single-Space Analysis C Results.

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
0,0,00	3753	3753	274	14278	4184	21784	4458
4,0,00	2872	2872	214	14743	4321	20487	4535
4,0,12-12	2872	2872	214	14743	4321	20487	4535
4,0,16-16	2872	2872	214	14743	4321	20487	4535
4,0,4-4	2872	2872	214	14743	4321	20487	4535
4,0,8-8	2872	2872	214	14743	4321	20487	4535
4,12,00	2915	2915	217	14681	4303	20511	4520
4,12,12-12	2915	2915	217	14681	4303	20511	4520
4,12,16-16	2915	2915	217	14681	4303	20511	4520
4,12,4-4	2915	2915	217	14681	4303	20511	4520
4,12,8-8	2915	2915	217	14681	4303	20511	4520
4,16,00	2915	2915	217	14681	4303	20511	4520
4,16,12-12	2915	2915	217	14681	4303	20511	4520
4,16,16-16	2915	2915	217	14681	4303	20511	4520
4,16,4-4	2915	2915	217	14681	4303	20511	4520
4,16,8-8	2915	2915	217	14681	4303	20511	4520
4,4,00	2911	2911	216	14656	4295	20478	4511
4,4,12-12	2911	2911	216	14656	4295	20478	4511
4,4,16-16	2911	2911	216	14656	4295	20478	4511
4,4,4-4	2911	2911	216	14656	4295	20478	4511
4,4,8-8	2911	2911	216	14656	4295	20478	4511
4,8,00	2915	2915	217	14681	4303	20511	4520
4,8,12-12	2915	2915	217	14681	4303	20511	4520
4,8,16-16	2915	2915	217	14681	4303	20511	4520
4,8,4-4	2915	2915	217	14681	4303	20511	4520
4,8,8-8	2915	2915	217	14681	4303	20511	4520
8,0,00	2816	2816	210	14852	4353	20484	4563
8,0,12-12	2815	2815	210	14852	4353	20482	4563
8,0,16-16	2815	2815	210	14852	4353	20482	4563
8,0,4-4	2815	2815	210	14852	4353	20482	4563
8,0,8-8	2815	2815	210	14852	4353	20482	4563
8,12,00	2912	2912	216	14670	4299	20494	4515

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
8,12,12-12	2912	2912	216	14670	4299	20494	4515
8,12,16-16	2912	2912	216	14670	4299	20494	4515
8,12,4-4	2912	2912	216	14670	4299	20494	4515
8,12,8-8	2912	2912	216	14670	4299	20494	4515
8,16,00	2915	2915	217	14681	4303	20511	4520
8,16,12-12	2915	2915	217	14681	4303	20511	4520
8,16,16-16	2915	2915	217	14681	4303	20511	4520
8,16,4-4	2915	2915	217	14681	4303	20511	4520
8,16,8-8	2915	2915	217	14681	4303	20511	4520
8,4,00	2868	2868	213	14723	4315	20459	4528
8,4,12-12	2868	2868	213	14723	4315	20459	4528
8,4,16-16	2868	2868	213	14723	4315	20459	4528
8,4,4-4	2868	2868	213	14723	4315	20459	4528
8,4,8-8	2868	2868	213	14723	4315	20459	4528
8,8,00	2899	2899	215	14653	4295	20451	4510
8,8,12-12	2899	2899	215	14653	4295	20451	4510
8,8,16-16	2899	2899	215	14653	4295	20451	4510
8,8,4-4	2899	2899	215	14653	4295	20451	4510
8,8,8-8	2899	2899	215	14653	4295	20451	4510
12,0,00	2762	2762	206	14852	4353	20376	4559
12,0,12-12	2762	2762	206	14871	4358	20395	4564
12,0,16-16	2762	2762	206	14871	4358	20395	4564
12,0,4-4	2762	2762	206	14871	4358	20395	4564
12,0,8-8	2762	2762	206	14871	4358	20395	4564
12,12,00	2882	2882	214	14678	4302	20442	4516
12,12,12-12	2882	2882	214	14676	4301	20440	4515
12,12,16-16	2882	2882	214	14676	4301	20440	4515
12,12,4-4	2882	2882	214	14676	4301	20440	4515
12,12,8-8	2882	2882	214	14676	4301	20440	4515
12,16,00	2901	2901	216	14678	4302	20480	4518
12,16,12-12	2901	2901	216	14679	4302	20481	4518
12,16,16-16	2901	2901	216	14679	4302	20481	4518
12,16,4-4	2901	2901	216	14679	4302	20481	4518
12,16,8-8	2901	2901	216	14679	4302	20481	4518
12,4,00	2802	2802	209	14810	4340	20414	4549

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
12,4,12-12	2800	2800	209	14815	4342	20415	4551
12,4,16-16	2800	2800	209	14815	4342	20415	4551
12,4,4-4	2800	2800	209	14815	4342	20415	4551
12,4,8-8	2800	2800	209	14815	4342	20415	4551
12,8,00	2854	2854	212	14655	4295	20363	4507
12,8,12-12	2853	2853	212	14658	4296	20364	4508
12,8,16-16	2853	2853	212	14658	4296	20364	4508
12,8,4-4	2853	2853	212	14658	4296	20364	4508
12,8,8-8	2853	2853	212	14658	4296	20364	4508
16,0,00	2711	2711	202	14958	4384	20380	4586
16,0,12-12	2708	2708	202	14971	4388	20387	4590
16,0,16-16	2708	2708	202	14971	4388	20387	4590
16,0,4-4	2709	2709	202	14973	4388	20391	4590
16,0,8-8	2708	2708	202	14971	4388	20387	4590
16,12,00	2835	2835	211	14654	4295	20324	4506
16,12,12-12	2835	2835	211	14663	4297	20333	4508
16,12,16-16	2835	2835	211	14663	4297	20333	4508
16,12,4-4	2834	2834	211	14662	4297	20330	4508
16,12,8-8	2835	2835	211	14663	4297	20333	4508
16,16,00	2869	2869	213	14659	4296	20397	4509
16,16,12-12	2868	2868	213	14660	4296	20396	4509
16,16,16-16	2868	2868	213	14660	4296	20396	4509
16,16,4-4	2868	2868	213	14660	4296	20396	4509
16,16,8-8	2868	2868	213	14660	4296	20396	4509
16,4,00	2753	2753	205	14833	4347	20339	4552
16,4,12-12	2755	2755	205	14829	4346	20339	4551
16,4,16-16	2755	2755	205	14829	4346	20339	4551
16,4,4-4	2754	2754	205	14830	4346	20338	4551
16,4,8-8	2755	2755	205	14829	4346	20339	4551
16,8,00	2793	2793	208	14796	4336	20382	4544
16,8,12-12	2791	2791	208	14802	4338	20384	4546
16,8,16-16	2791	2791	208	14802	4338	20384	4546
16,8,4-4	2791	2791	208	14802	4338	20384	4546
16,8,8-8	2791	2791	208	14802	4338	20384	4546
20,0,00	2657	2657	199	15033	4406	20347	4605

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
20,0,12-12	2651	2651	198	15037	4407	20339	4605
20,0,16-16	2651	2651	198	15037	4407	20339	4605
20,0,4-4	2652	2652	198	15049	4410	20353	4608
20,0,8-8	2651	2651	198	15037	4407	20339	4605
20,12,00	2798	2798	208	14697	4307	20293	4515
20,12,12-12	2796	2796	208	14712	4312	20304	4520
20,12,16-16	2796	2796	208	14712	4312	20304	4520
20,12,4-4	2796	2796	208	14712	4312	20304	4520
20,12,8-8	2796	2796	208	14712	4312	20304	4520
20,16,00	2823	2823	210	14660	4296	20306	4506
20,16,12-12	2820	2820	210	14641	4291	20281	4501
20,16,16-16	2820	2820	210	14641	4291	20281	4501
20,16,4-4	2820	2820	210	14641	4291	20281	4501
20,16,8-8	2820	2820	210	14641	4291	20281	4501
20,4,00	2712	2712	202	14854	4353	20278	4555
20,4,12-12	2710	2710	202	14839	4349	20259	4551
20,4,16-16	2710	2710	202	14839	4349	20259	4551
20,4,4-4	2711	2711	202	14863	4356	20285	4558
20,4,8-8	2710	2710	202	14839	4349	20259	4551
20,8,00	2757	2757	205	14720	4314	20234	4519
20,8,12-12	2752	2752	205	14741	4320	20245	4525
20,8,16-16	2752	2752	205	14741	4320	20245	4525
20,8,4-4	2752	2752	205	14752	4323	20256	4528
20,8,8-8	2752	2752	205	14741	4320	20245	4525
24,0,00	2614	2614	196	15032	4406	20260	4602
24,0,12-12	2608	2608	195	15044	4409	20260	4604
24,0,16-16	2608	2608	195	15044	4409	20260	4604
24,0,4-4	2610	2610	195	15021	4402	20241	4597
24,0,8-8	2608	2608	195	15033	4406	20249	4601
24,12,00	2749	2749	205	14667	4299	20165	4504
24,12,12-12	2744	2744	205	14683	4303	20171	4508
24,12,16-16	2744	2744	205	14683	4303	20171	4508
24,12,4-4	2748	2748	205	14674	4300	20170	4505
24,12,8-8	2745	2745	205	14675	4301	20165	4506
24,16,00	2786	2786	207	14755	4324	20327	4531

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
24,16,12-12	2784	2784	207	14710	4311	20278	4518
24,16,16-16	2784	2784	207	14710	4311	20278	4518
24,16,4-4	2784	2784	207	14721	4314	20289	4521
24,16,8-8	2785	2785	207	14710	4311	20280	4518
24,4,00	2665	2665	199	14982	4391	20312	4590
24,4,12-12	2658	2658	199	14959	4384	20275	4583
24,4,16-16	2658	2658	199	14959	4384	20275	4583
24,4,4-4	2662	2662	199	14957	4384	20281	4583
24,4,8-8	2659	2659	199	14959	4384	20277	4583
24,8,00	2710	2710	202	14797	4337	20217	4539
24,8,12-12	2707	2707	202	14812	4341	20226	4543
24,8,16-16	2707	2707	202	14812	4341	20226	4543
24,8,4-4	2709	2709	202	14793	4335	20211	4537
24,8,8-8	2659	2659	199	14959	4384	20277	4583
28,0,00	2572	2572	193	15128	4434	20272	4627
28,0,12-12	2566	2566	192	15142	4438	20274	4630
28,0,16-16	2566	2566	192	15142	4438	20274	4630
28,0,4-4	2568	2568	192	15109	4428	20245	4620
28,0,8-8	2567	2567	192	15110	4428	20244	4620
28,12,00	2708	2708	202	14838	4349	20254	4551
28,12,12-12	2701	2701	202	14815	4342	20217	4544
28,12,16-16	2701	2701	202	14815	4342	20217	4544
28,12,4-4	2704	2704	202	14819	4343	20227	4545
28,12,8-8	2701	2701	202	14806	4339	20208	4541
28,16,00	2745	2745	205	14748	4322	20238	4527
28,16,12-12	2739	2739	204	14757	4325	20235	4529
28,16,16-16	2739	2739	204	14757	4325	20235	4529
28,16,4-4	2741	2741	204	14739	4320	20221	4524
28,16,8-8	2740	2740	204	14749	4322	20229	4526
28,4,00	2617	2617	196	14960	4384	20194	4580
28,4,12-12	2609	2609	195	14981	4390	20199	4585
28,4,16-16	2609	2609	195	14981	4390	20199	4585
28,4,4-4	2612	2612	196	14974	4388	20198	4584
28,4,8-8	2610	2610	195	14991	4394	20211	4589
28,8,00	2665	2665	199	14896	4365	20226	4564

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
28,8,12-12	2657	2657	199	14972	4388	20286	4587
28,8,16-16	2657	2657	199	14972	4388	20286	4587
28,8,4-4	2661	2661	199	14920	4372	20242	4571
28,8,8-8	2659	2659	199	14971	4388	20289	4587
32,0,00	2540	2540	191	15224	4462	20304	4653
32,0,12-12	2534	2534	190	15185	4450	20253	4640
32,0,16-16	2534	2534	190	15185	4450	20253	4640
32,0,4-4	2536	2536	190	15187	4451	20259	4641
32,0,8-8	2535	2535	190	15180	4449	20250	4639
32,12,00	2665	2665	199	14919	4372	20249	4571
32,12,12-12	2657	2657	199	14910	4370	20224	4569
32,12,16-16	2657	2657	199	14914	4371	20228	4570
32,12,4-4	2661	2661	199	14915	4371	20237	4570
32,12,8-8	2659	2659	199	14916	4371	20234	4570
32,16,00	2701	2701	202	14774	4330	20176	4532
32,16,12-12	2696	2696	201	14742	4320	20134	4521
32,16,16-16	2696	2696	201	14746	4321	20138	4522
32,16,4-4	2701	2701	202	14750	4323	20152	4525
32,16,8-8	2697	2697	201	14738	4319	20132	4520
32,4,00	2575	2575	193	15067	4416	20217	4609
32,4,12-12	2566	2566	192	15105	4427	20237	4619
32,4,16-16	2565	2565	192	15113	4429	20243	4621
32,4,4-4	2571	2571	193	15109	4428	20251	4621
32,4,8-8	2566	2566	192	15098	4425	20230	4617
32,8,00	2622	2622	196	15034	4406	20278	4602
32,8,12-12	2615	2615	196	15004	4397	20234	4593
32,8,16-16	2615	2615	196	15009	4399	20239	4595
32,8,4-4	2618	2618	196	14977	4389	20213	4585
32,8,8-8	2615	2615	196	14990	4393	20220	4589
36,0,00	2507	2507	188	15174	4447	20188	4635
36,0,12-12	2501	2501	188	15131	4435	20133	4623
36,0,16-16	2501	2501	188	15148	4439	20150	4627
36,0,4-4	2505	2505	188	15137	4436	20147	4624
36,0,8-8	2504	2504	188	15151	4440	20159	4628
36,12,00	2631	2631	197	14931	4376	20193	4573

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
36,12,12-12	2623	2623	196	14907	4369	20153	4565
36,12,16-16	2621	2621	196	14927	4375	20169	4571
36,12,4-4	2628	2628	197	14947	4380	20203	4577
36,12,8-8	2625	2625	196	14919	4372	20169	4568
36,16,00	2662	2662	199	14913	4370	20237	4569
36,16,12-12	2658	2658	199	14901	4367	20217	4566
36,16,16-16	2655	2655	198	14890	4364	20200	4562
36,16,4-4	2659	2659	199	14865	4356	20183	4555
36,16,8-8	2657	2657	199	14887	4363	20201	4562
36,4,00	2550	2550	191	15135	4436	20235	4627
36,4,12-12	2543	2543	191	15179	4448	20265	4639
36,4,16-16	2542	2542	191	15201	4455	20285	4646
36,4,4-4	2549	2549	191	15176	4448	20274	4639
36,4,8-8	2544	2544	191	15170	4446	20258	4637
36,8,00	2585	2585	194	15018	4401	20188	4595
36,8,12-12	2578	2578	193	15009	4399	20165	4592
36,8,16-16	2577	2577	193	15021	4402	20175	4595
36,8,4-4	2581	2581	193	15018	4401	20180	4594
36,8,8-8	2579	2579	193	15039	4407	20197	4600
40,0,00	2483	2483	187	15164	4444	20130	4631
40,0,12-12	2468	2468	186	15178	4448	20114	4634
40,0,16-16	2467	2467	185	15186	4451	20120	4636
40,0,4-4	2474	2474	186	15180	4449	20128	4635
40,0,8-8	2470	2470	186	15188	4451	20128	4637
40,12,00	2594	2594	194	14997	4395	20185	4589
40,12,12-12	2585	2585	194	14931	4376	20101	4570
40,12,16-16	2582	2582	193	14941	4379	20105	4572
40,12,4-4	2591	2591	194	14869	4358	20051	4552
40,12,8-8	2587	2587	194	14927	4375	20101	4569
40,16,00	2630	2630	197	14849	4352	20109	4549
40,16,12-12	2622	2622	196	14873	4359	20117	4555
40,16,16-16	2619	2619	196	14841	4350	20079	4546
40,16,4-4	2627	2627	196	14881	4361	20135	4557
40,16,8-8	2625	2625	196	14875	4359	20125	4555
40,4,00	2522	2522	189	15165	4444	20209	4633

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
40,4,12-12	2511	2511	189	15132	4435	20154	4624
40,4,16-16	2510	2510	189	15123	4432	20143	4621
40,4,4-4	2518	2518	189	15120	4431	20156	4620
40,4,8-8	2513	2513	189	15103	4426	20129	4615
40,8,00	2555	2555	192	15150	4440	20260	4632
40,8,12-12	2546	2546	191	15129	4434	20221	4625
40,8,16-16	2546	2546	191	15129	4434	20221	4625
40,8,4-4	2552	2552	191	15137	4436	20241	4627
40,8,8-8	2549	2549	191	15140	4437	20238	4628
44,0,00	2464	2464	185	15326	4491	20254	4676
44,0,12-12	2448	2448	184	15307	4486	20203	4670
44,0,16-16	2447	2447	184	15320	4490	20214	4674
44,0,4-4	2456	2456	185	15337	4495	20249	4680
44,0,8-8	2452	2452	184	15300	4484	20204	4668
44,12,00	2564	2564	192	15062	4414	20190	4606
44,12,12-12	2551	2551	191	15088	4422	20190	4613
44,12,16-16	2549	2549	191	15064	4415	20162	4606
44,12,4-4	2558	2558	192	15085	4421	20201	4613
44,12,8-8	2553	2553	191	15086	4421	20192	4612
44,16,00	2610	2610	195	14890	4364	20110	4559
44,16,12-12	2597	2597	194	14929	4375	20123	4569
44,16,16-16	2594	2594	194	14914	4371	20102	4565
44,16,4-4	2600	2600	195	14888	4363	20088	4558
44,16,8-8	2599	2599	195	14904	4368	20102	4563
44,4,00	2489	2489	187	15117	4430	20095	4617
44,4,12-12	2477	2477	186	15142	4438	20096	4624
44,4,16-16	2475	2475	186	15139	4437	20089	4623
44,4,4-4	2485	2485	187	15112	4429	20082	4616
44,4,8-8	2478	2478	186	15144	4438	20100	4624
44,8,00	2534	2534	190	15146	4439	20214	4629
44,8,12-12	2523	2523	189	15120	4431	20166	4620
44,8,16-16	2520	2520	189	15125	4433	20165	4622
44,8,4-4	2528	2528	190	15137	4436	20193	4626
44,8,8-8	2525	2525	189	15121	4431	20171	4620
48,0,00	2437	2437	183	15376	4506	20250	4689

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
48,0,12-12	2421	2421	182	15453	4529	20295	4711
48,0,16-16	2421	2421	182	15456	4530	20298	4712
48,0,4-4	2431	2431	183	15403	4514	20265	4697
48,0,8-8	2425	2425	183	15410	4516	20260	4699
48,12,00	2544	2544	191	15153	4441	20241	4632
48,12,12-12	2531	2531	190	15175	4447	20237	4637
48,12,16-16	2528	2528	190	15187	4451	20243	4641
48,12,4-4	2538	2538	190	15166	4445	20242	4635
48,12,8-8	2534	2534	190	15176	4448	20244	4638
48,16,00	2574	2574	193	15022	4403	20170	4596
48,16,12-12	2563	2563	192	15030	4405	20156	4597
48,16,16-16	2561	2561	192	15016	4401	20138	4593
48,16,4-4	2569	2569	193	15031	4405	20169	4598
48,16,8-8	2566	2566	192	15024	4403	20156	4595
48,4,00	2475	2475	186	15184	4450	20134	4636
48,4,12-12	2460	2460	185	15247	4468	20167	4653
48,4,16-16	2459	2459	185	15230	4463	20148	4648
48,4,4-4	2469	2469	186	15173	4447	20111	4633
48,4,8-8	2462	2462	185	15240	4466	20164	4651
48,8,00	2501	2501	188	15100	4425	20102	4613
48,8,12-12	2487	2487	187	15125	4433	20099	4620
48,8,16-16	2486	2486	187	15139	4437	20111	4624
48,8,4-4	2495	2495	187	15131	4434	20121	4621
48,8,8-8	2491	2491	187	15153	4441	20135	4628
52,0,00	2427	2427	183	15480	4537	20334	4720
52,0,12-12	2411	2411	182	15530	4551	20352	4733
52,0,16-16	2410	2410	181	15542	4555	20362	4736
52,0,4-4	2418	2418	182	15487	4539	20323	4721
52,0,8-8	2413	2413	182	15517	4548	20343	4730
52,12,00	2523	2523	189	15150	4440	20196	4629
52,12,12-12	2508	2508	188	15151	4440	20167	4628
52,12,16-16	2505	2505	188	15186	4450	20196	4638
52,12,4-4	2523	2523	189	15150	4440	20196	4629
52,12,8-8	2513	2513	189	15171	4446	20197	4635
52,16,00	2547	2547	191	15106	4427	20200	4618

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
52,16,12-12	2535	2535	190	15054	4412	20124	4602
52,16,16-16	2533	2533	190	15052	4411	20118	4601
52,16,4-4	2525	2525	189	15104	4427	20154	4616
52,16,8-8	2539	2539	190	15096	4424	20174	4614
52,4,00	2456	2456	185	15345	4497	20257	4682
52,4,12-12	2442	2442	184	15445	4527	20329	4711
52,4,16-16	2441	2441	184	15471	4534	20353	4718
52,4,4-4	2452	2452	184	15377	4506	20281	4690
52,4,8-8	2444	2444	184	15423	4520	20311	4704
52,8,00	2482	2482	187	15104	4427	20068	4614
52,8,12-12	2465	2465	185	15249	4469	20179	4654
52,8,16-16	2463	2463	185	15224	4462	20150	4647
52,8,4-4	2477	2477	186	15086	4421	20040	4607
52,8,8-8	2470	2470	186	15189	4451	20129	4637
56,0,00	2416	2416	182	15493	4541	20325	4723
56,0,12-12	2400	2400	181	15526	4550	20326	4731
56,0,16-16	2400	2400	181	15502	4543	20302	4724
56,0,4-4	2409	2409	181	15482	4537	20300	4718
56,0,8-8	2403	2403	181	15501	4543	20307	4724
56,12,00	2491	2491	187	15091	4423	20073	4610
56,12,12-12	2477	2477	186	15100	4425	20054	4611
56,12,16-16	2474	2474	186	15089	4422	20037	4608
56,12,4-4	2486	2486	187	15047	4410	20019	4597
56,12,8-8	2480	2480	186	15063	4415	20023	4601
56,16,00	2527	2527	190	15104	4427	20158	4617
56,16,12-12	2515	2515	189	15128	4433	20158	4622
56,16,16-16	2511	2511	189	15148	4440	20170	4629
56,16,4-4	2525	2525	189	15104	4427	20154	4616
56,16,8-8	2519	2519	189	15097	4425	20135	4614
56,4,00	2435	2435	183	15487	4539	20357	4722
56,4,12-12	2417	2417	182	15541	4555	20375	4737
56,4,16-16	2415	2415	182	15534	4553	20364	4735
56,4,4-4	2427	2427	183	15451	4528	20305	4711
56,4,8-8	2422	2422	182	15463	4532	20307	4714
56,8,00	2467	2467	186	15256	4471	20190	4657

5 WINDOWS OF 5 BY 6 FEET							
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD	TOTAL INPUT
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)	(kWh)
56,8,12-12	2448	2448	184	15315	4488	20211	4672
56,8,16-16	2446	2446	184	15314	4488	20206	4672
56,8,4-4	2461	2461	185	15275	4477	20197	4662
56,8,8-8	2454	2454	185	15307	4486	20215	4671
60,0,00	2401	2401	181	15512	4546	20314	4727
60,0,12-12	2381	2381	179	15497	4542	20259	4721
60,0,16-16	2379	2379	179	15497	4542	20255	4721
60,0,4-4	2393	2393	180	15462	4531	20248	4711
60,0,8-8	2387	2387	180	15492	4540	20266	4720
60,12,00	2478	2478	186	15162	4444	20118	4630
60,12,12-12	2463	2463	185	15242	4467	20168	4652
60,12,16-16	2459	2459	185	15247	4468	20165	4653
60,12,4-4	2473	2473	186	15226	4462	20172	4648
60,12,8-8	2469	2469	186	15192	4452	20130	4638
60,16,00	2508	2508	188	15054	4412	20070	4600
60,16,12-12	2493	2493	187	15104	4426	20090	4613
60,16,16-16	2491	2491	187	15146	4439	20128	4626
60,16,4-4	2502	2502	188	15087	4422	20091	4610
60,16,8-8	2498	2498	188	15111	4429	20107	4617
60,4,00	2426	2426	183	15501	4543	20353	4726
60,4,12-12	2407	2407	181	15481	4537	20295	4718
60,4,16-16	2406	2406	181	15514	4547	20326	4728
60,4,4-4	2417	2417	182	15521	4549	20355	4731
60,4,8-8	2411	2411	182	15496	4541	20318	4723
60,8,00	2445	2445	184	15388	4510	20278	4694
60,8,12-12	2427	2427	183	15472	4535	20326	4718
60,8,16-16	2425	2425	183	15455	4529	20305	4712
60,8,4-4	2438	2438	183	15372	4505	20248	4688
60,8,8-8	2434	2434	183	15384	4509	20252	4692
					MIN	20019	
					MAX	21784	

C.4 Single-Space Analysis D Results

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
0,0,00	4297	4297	314	16348	4791	24943
4,12,00	3352	3352	250	16880	4948	23584
4,12,12-12	3351	3351	249	16877	4947	23579
4,12,16-16	3351	3351	249	16874	4946	23575
4,12,4-4	3350	3350	249	16871	4945	23571
4,12,8-8	3349	3349	249	16868	4944	23567
4,16,00	3349	3349	249	16866	4943	23563
4,16,12-12	3348	3348	249	16863	4942	23559
4,16,16-16	3348	3348	249	16860	4942	23555
4,16,4-4	3347	3347	249	16857	4941	23551
4,16,8-8	3346	3346	249	16854	4940	23547
4,8,00	3346	3346	249	16851	4939	23543
4,8,12-12	3345	3345	249	16848	4938	23538
4,8,16-16	3345	3345	249	16845	4937	23534
4,8,4-4	3344	3344	249	16842	4936	23530
4,8,8-8	3344	3344	249	16839	4936	23526
8,16,00	3343	3343	249	16836	4935	23522
8,16,12-12	3342	3342	249	16833	4934	23518
8,16,16-16	3342	3342	249	16830	4933	23514
8,16,4-4	3341	3341	249	16827	4932	23510
8,16,8-8	3341	3341	249	16824	4931	23506
8,12,00	3337	3337	247	16809	4926	23482
8,12,12-12	3336	3336	247	16806	4925	23478
8,12,16-16	3335	3335	247	16803	4924	23474
8,12,4-4	3335	3335	247	16800	4923	23470
8,12,8-8	3334	3334	247	16797	4922	23466
4,0,00	3288	3288	245	16878	4947	23454
4,0,12-12	3287	3287	245	16875	4946	23449
4,0,16-16	3287	3287	245	16872	4945	23445
4,0,4-4	3286	3286	245	16869	4944	23441
4,0,8-8	3286	3286	245	16866	4943	23437

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
8,0,00	3221	3221	240	16988	4979	23430
8,0,12-12	3219	3219	240	16985	4978	23423
8,0,16-16	3219	3219	240	16982	4977	23419
8,0,4-4	3218	3218	240	16979	4976	23415
8,0,8-8	3218	3218	240	16976	4975	23411
12,16,12-12	3315	3315	247	16775	4916	23406
12,16,16-16	3315	3315	247	16772	4915	23402
12,16,4-4	3314	3314	247	16769	4915	23397
12,16,8-8	3314	3314	247	16766	4914	23393
12,16,00	3313	3313	247	16762	4913	23388
4,4,00	3324	3324	247	16734	4904	23382
4,4,12-12	3323	3323	247	16731	4903	23378
4,4,16-16	3323	3323	247	16728	4902	23374
4,4,4-4	3322	3322	246	16725	4901	23369
4,4,8-8	3321	3321	246	16722	4901	23365
8,4,00	3272	3272	243	16796	4923	23340
8,4,12-12	3271	3271	243	16793	4922	23336
8,4,16-16	3271	3271	243	16790	4921	23331
8,4,4-4	3270	3270	243	16787	4920	23327
8,4,8-8	3270	3270	243	16784	4919	23323
8,8,00	3304	3304	245	16701	4895	23310
8,8,12-12	3304	3304	245	16699	4895	23306
8,8,16-16	3303	3303	245	16696	4894	23302
8,8,4-4	3303	3303	245	16693	4893	23298
8,8,8-8	3302	3302	245	16690	4892	23294
12,12,00	3282	3282	244	16715	4899	23279
12,12,12-12	3281	3281	244	16710	4897	23273
12,12,16-16	3281	3281	244	16707	4896	23269
12,12,4-4	3280	3280	244	16704	4895	23265
12,12,8-8	3280	3280	244	16701	4895	23261
12,4,12-12	3186	3186	238	16857	4940	23228
12,4,16-16	3185	3185	238	16854	4939	23224
12,4,4-4	3185	3185	238	16851	4939	23220
12,4,8-8	3184	3184	238	16848	4938	23216

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
12,4,00	3186	3186	238	16839	4935	23211
16,16,00	3261	3261	242	16664	4884	23187
16,16,12-12	3260	3260	242	16663	4883	23182
16,16,16-16	3259	3259	242	16660	4882	23178
16,16,4-4	3259	3259	242	16657	4881	23174
16,16,8-8	3258	3258	242	16654	4880	23170
12,0,12-12	3137	3137	234	16890	4950	23165
12,0,16-16	3137	3137	234	16888	4949	23161
12,0,4-4	3136	3136	234	16885	4948	23156
12,0,8-8	3135	3135	234	16882	4947	23152
16,0,4-4	3075	3075	229	16994	4980	23144
16,0,12-12	3073	3073	229	16989	4980	23135
16,0,16-16	3072	3072	229	16986	4979	23131
16,0,8-8	3072	3072	229	16983	4978	23127
16,8,12-12	3166	3166	236	16788	4920	23120
16,8,16-16	3165	3165	236	16785	4919	23115
16,8,4-4	3164	3164	236	16783	4918	23111
16,8,8-8	3164	3164	236	16780	4918	23107
16,8,00	3166	3166	236	16770	4914	23101
16,0,00	3072	3072	229	16950	4968	23095
12,0,00	3129	3129	233	16827	4932	23086
56,4,12-12	2738	2738	206	17605	5160	23081
12,8,12-12	3231	3231	240	16602	4866	23064
12,8,16-16	3231	3231	240	16599	4865	23060
12,8,4-4	3230	3230	240	16596	4864	23056
12,8,8-8	3230	3230	240	16593	4863	23052
56,4,16-16	2733	2733	206	17581	5153	23048
12,8,00	3230	3230	240	16584	4860	23043
52,0,16-16	2727	2727	205	17584	5154	23038
56,4,00	2754	2754	207	17519	5135	23028
60,4,4-4	2734	2734	206	17554	5145	23022
20,0,4-4	2999	2999	224	17017	4987	23015
52,4,16-16	2760	2760	208	17492	5126	23011
60,4,00	2742	2742	207	17522	5135	23007

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
52,0,12-12	2725	2725	206	17552	5144	23002
20,0,00	3002	3002	225	16987	4979	22992
52,0,8-8	2726	2726	206	17531	5138	22984
16,4,00	3110	3110	232	16755	4910	22975
16,4,12-12	3111	3111	232	16748	4908	22971
16,4,16-16	3111	3111	231	16745	4908	22967
16,4,8-8	3110	3110	231	16742	4907	22963
20,0,12-12	2992	2992	224	16974	4975	22959
20,0,16-16	2992	2992	223	16971	4974	22955
20,0,8-8	2991	2991	223	16968	4973	22951
16,4,4-4	3107	3107	231	16731	4903	22945
52,0,00	2738	2738	206	17461	5118	22937
16,12,12-12	3197	3197	238	16537	4846	22932
16,12,16-16	3197	3197.	238	16534	4845	22927
16,12,8-8	3196	3196	238	16531	4844	22923
16,12,4-4	3194	3194	238	16527	4844	22916
52,4,12-12	2752	2752	207	17407	5102	22911
24,16,00	3139	3139	233	16626	4872	22904
56,0,12-12	2704	2704	204	17492	5126	22899
60,4,16-16	2710	2710	204	17475	5122	22895
60,8,12-12	2733	2733	206	17425	5107	22891
56,0,00	2720	2720	205	17445	5113	22886
16,12,00	3192	3192	238	16497	4835	22881
52,0,4-4	2722	2722	205	17432	5109	22876
60,4,8-8	2713	2713	205	17439	5110	22866
60,0,00	2702	2702	204	17454	5115	22857
24,4,00	2998	2998	224	16855	4940	22851
52,4,8-8	2749	2749	207	17348	5084	22846
56,0,8-8	2702	2702	204	17432	5109	22837
56,4,8-8	2723	2723	205	17387	5096	22833
20,16,00	3174	3174	236	16481	4830	22828
56,4,4-4	2728	2728	206	17367	5089	22823
60,8,16-16	2725	2725	206	17368	5090	22819
20,12,12-12	3142	3142	234	16530	4845	22814

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
20,12,16-16	3141	3141	234	16527	4844	22810
20,12,4-4	3140	3140	234	16525	4843	22805
20,12,8-8	3140	3140	234	16522	4842	22801
32,0,00	2852	2852	214	17094	5010	22797
56,0,16-16	2694	2694	203	17403	5100	22791
56,0,4-4	2704	2704	203	17377	5092	22785
48,0,16-16	2717	2717	204	17345	5084	22778
48,0,12-12	2716	2716	204	17338	5082	22771
60,4,12-12	2700	2700	203	17367	5090	22767
20,12,00	3138	3138	233	16484	4831	22761
24,16,4-4	3122	3122	232	16508	4838	22752
28,8,8-8	2981	2981	223	16785	4920	22748
28,8,12-12	2978	2978	223	16784	4919	22741
28,8,16-16	2978	2978	223	16781	4918	22737
20,4,4-4	3038	3038	226	16655	4881	22731
36,4,16-16	2848	2848	214	17031	4991	22727
20,16,12-12	3159	3159	235	16401	4807	22719
20,16,16-16	3158	3158	235	16398	4806	22715
20,16,4-4	3158	3158	235	16395	4805	22711
20,16,8-8	3157	3157	235	16392	4804	22707
24,4,4-4	2980	2980	223	16743	4907	22703
52,4,4-4	2744	2744	206	17210	5043	22698
24,16,8-8	3116	3116	232	16460	4824	22693
20,4,00	3034	3034	226	16619	4870	22687
24,16,12-12	3114	3114	232	16455	4822	22683
24,16,16-16	3114	3114	232	16452	4821	22679
32,8,00	2932	2932	219	16811	4927	22675
60,8,00	2734	2734	206	17204	5042	22671
24,4,8-8	2972	2972	222	16721	4900	22666
24,8,8-8	2972	2972	222	16718	4900	22662
24,4,12-12	2970	2970	222	16715	4899	22655
24,4,16-16	2970	2970	222	16712	4898	22651
28,0,12-12	2866	2866	214	16914	4957	22646
28,0,16-16	2866	2866	214	16911	4956	22642

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
36,4,4-4	2846	2846	213	16946	4967	22638
28,0,00	2871	2871	215	16889	4950	22632
60,0,8-8	2664	2664	201	17292	5068	22621
36,4,12-12	2838	2838	213	16940	4964	22616
48,0,4-4	2713	2713	204	17187	5037	22612
24,0,00	2916	2916	219	16770	4915	22602
24,0,12-12	2909	2909	218	16780	4918	22598
24,0,16-16	2908	2908	217	16777	4917	22594
40,8,00	2849	2849	214	16892	4951	22590
48,0,8-8	2703	2703	204	17179	5034	22586
20,4,12-12	3021	3021	225	16540	4847	22581
20,4,16-16	3020	3020	225	16537	4847	22577
20,4,8-8	3019	3019	225	16534	4846	22573
32,0,4-4	2825	2825	212	16918	4958	22569
60,0,12-12	2652	2652	199	17261	5059	22564
36,4,8-8	2833	2833	213	16893	4951	22559
52,4,00	2735	2735	206	17085	5007	22554
20,8,4-4	3064	3064	228	16422	4812	22549
60,0,16-16	2648	2648	199	17248	5055	22544
28,12,00	3013	3013	225	16512	4840	22539
44,0,00	2741	2741	206	17052	4997	22535
32,0,12-12	2819	2819	211	16892	4950	22529
32,0,16-16	2818	2818	211	16889	4949	22525
60,8,8-8	2707	2707	203	17107	5014	22520
32,4,4-4	2858	2858	215	16798	4923	22515
32,0,8-8	2818	2818	211	16874	4946	22510
48,0,00	2708	2708	203	17089	5008	22506
24,0,8-8	2898	2898	217	16705	4896	22501
32,12,00	2961	2961	221	16575	4857	22497
44,0,4-4	2728	2728	205	17036	4993	22493
60,0,4-4	2658	2658	200	17172	5032	22487
60,8,4-4	2707	2707	203	17069	5002	22483
20,8,12-12	3055	3055	228	16365	4796	22476
20,8,16-16	3055	3055	228	16363	4795	22472

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
20,8,8-8	3054	3054	228	16360	4794	22468
28,0,4-4	2849	2849	213	16765	4913	22464
28,0,8-8	2848	2848	213	16763	4912	22459
48,12,8-8	2811	2811	211	16833	4934	22455
32,4,16-16	2845	2845	213	16760	4912	22449
48,12,16-16	2803	2803	211	16839	4935	22445
28,8,4-4	2950	2950	221	16540	4847	22440
48,12,4-4	2813	2813	211	16810	4927	22436
24,0,4-4	2892	2892	216	16646	4878	22431
40,8,4-4	2828	2828	212	16772	4915	22427
48,12,00	2818	2818	212	16786	4920	22423
32,8,16-16	2896	2896	217	16624	4872	22417
28,16,00	3040	3040	227	16332	4786	22412
40,8,8-8	2822	2822	211	16763	4913	22408
32,12,4-4	2946	2946	220	16511	4839	22402
32,4,12-12	2840	2840	213	16718	4900	22398
36,16,00	2946	2946	220	16503	4836	22394
48,12,12-12	2800	2800	210	16790	4920	22390
28,16,12-12	3030	3030	226	16324	4784	22384
28,16,16-16	3029	3029	226	16321	4783	22380
36,4,00	2820	2820	211	16736	4905	22376
20,8,00	3048	3048	227	16274	4770	22371
32,12,8-8	2939	2939	220	16488	4832	22367
32,8,12-12	2890	2890	217	16582	4860	22363
32,4,8-8	2835	2835	212	16683	4890	22354
28,16,8-8	3027	3027	225	16295	4775	22349
32,12,16-16	2935	2935	220	16474	4828	22344
28,12,4-4	2986	2986	223	16366	4796	22339
24,8,12-12	2989	2989	223	16355	4793	22334
24,8,16-16	2989	2989	223	16352	4792	22330
28,8,00	2942	2942	220	16442	4818	22325
32,12,12-12	2932	2932	220	16455	4823	22319
28,16,4-4	3024	3024	225	16263	4767	22312
40,8,12-12	2809	2809	211	16690	4892	22308

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
40,8,16-16	2808	2808	211	16687	4891	22304
32,8,8-8	2884	2884	216	16531	4845	22299
24,8,00	2988	2988	223	16315	4782	22291
28,12,12-12	2978	2978	223	16332	4787	22287
28,12,16-16	2977	2977	223	16329	4786	22283
32,4,00	2838	2838	213	16604	4866	22279
36,16,12-12	2929	2929	219	16418	4812	22275
56,8,8-8	2703	2703	204	16862	4942	22269
44,0,16-16	2695	2695	203	16873	4945	22264
44,8,00	2790	2790	209	16679	4888	22260
32,8,4-4	2882	2882	216	16490	4832	22255
24,8,4-4	2982	2982	222	16284	4772	22248
28,4,8-8	2873	2873	215	16499	4836	22244
56,8,12-12	2694	2694	202	16853	4939	22240
40,4,00	2775	2775	208	16685	4889	22234
28,12,8-8	2971	2971	222	16287	4773	22229
56,8,16-16	2690	2690	202	16842	4936	22223
44,0,8-8	2696	2696	202	16824	4931	22216
36,12,4-4	2889	2889	217	16433	4815	22211
44,0,12-12	2691	2691	202	16825	4931	22207
36,16,8-8	2920	2920	219	16361	4795	22201
44,12,4-4	2811	2811	211	16575	4858	22197
36,16,16-16	2917	2917	218	16358	4794	22192
52,16,00	2798	2798	210	16592	4863	22188
28,4,12-12	2865	2865	214	16452	4821	22183
28,4,16-16	2865	2865	214	16449	4820	22179
28,4,4-4	2867	2867	215	16438	4817	22173
36,8,8-8	2831	2831	212	16507	4837	22168
52,12,8-8	2758	2758	207	16649	4879	22164
56,8,4-4	2700	2700	203	16760	4912	22160
52,12,00	2768	2768	207	16620	4871	22155
52,12,16-16	2747	2747	206	16656	4881	22151
52,12,4-4	2767	2767	207	16613	4869	22147
28,4,00	2869	2869	215	16402	4807	22141

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
36,12,00	2884	2884	216	16367	4797	22136
44,8,4-4	2771	2771	208	16590	4862	22132
44,12,8-8	2798	2798	209	16531	4845	22126
44,12,00	2809	2809	210	16502	4836	22120
44,12,12-12	2794	2794	209	16527	4844	22116
56,8,00	2702	2702	204	16708	4897	22112
36,0,00	2745	2745	206	16616	4869	22106
36,8,00	2830	2830	212	16442	4818	22102
40,12,00	2839	2839	212	16416	4811	22095
36,16,4-4	2910	2910	218	16268	4767	22088
36,8,4-4	2824	2824	211	16433	4816	22081
52,8,12-12	2697	2697	202	16682	4889	22076
32,16,00	2954	2954	221	16160	4736	22069
36,8,16-16	2818	2818	211	16427	4814	22063
52,16,8-8	2776	2776	208	16506	4837	22058
60,12,4-4	2703	2703	203	16645	4878	22052
24,12,12-12	2999	2999	224	16049	4703	22047
24,12,16-16	2999	2999	224	16046	4702	22043
44,8,8-8	2759	2759	207	16521	4841	22039
24,12,4-4	3002	3002	224	16030	4697	22034
48,16,00	2811	2811	211	16407	4809	22030
56,16,16-16	2742	2742	206	16542	4848	22026
36,12,16-16	2862	2862	214	16297	4777	22021
36,12,8-8	2865	2865	214	16286	4772	22016
48,16,4-4	2804	2804	211	16405	4808	22012
60,12,12-12	2688	2688	202	16632	4874	22007
48,4,12-12	2684	2684	202	16634	4875	22002
52,12,12-12	2736	2736	205	16527	4843	21998
44,8,12-12	2752	2752	206	16490	4832	21993
24,12,00	2998	2998	224	15993	4688	21988
24,12,8-8	2993	2993	223	15999	4689	21984
36,8,12-12	2810	2810	210	16360	4795	21980
44,8,16-16	2746	2746	206	16483	4831	21976
60,12,16-16	2679	2679	202	16613	4868	21972

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	Central Cooling Coil Load	Central Cooling Eqpt Load	Central Unit Cooling Input	Central Heating Coil Load	Central Heating Coil Input	TOTAL LOAD
inch	(kBTU)	(kBTU)	(kWh)	(kBTU)	(kWh)	(kBTU)
48,4,8-8	2682	2682	202	16602	4865	21967
44,12,16-16	2776	2776	208	16408	4809	21960
36,0,8-8	2727	2727	205	16499	4835	21953
56,16,00	2751	2751	207	16445	4820	21948
56,16,12-12	2738	2738	206	16468	4826	21944
40,4,4-4	2741	2741	206	16457	4823	21938
48,16,12-12	2789	2789	209	16356	4794	21934
48,16,8-8	2792	2792	209	16346	4790	21930
40,4,12-12	2731	2731	206	16461	4824	21924
52,16,4-4	2746	2746	206	16427	4815	21919
56,16,4-4	2746	2746	206	16424	4814	21915
36,12,12-12	2852	2852	213	16207	4750	21910
32,16,4-4	2936	2936	220	16033	4699	21905
36,0,16-16	2718	2718	204	16463	4824	21899
52,8,16-16	2676	2676	201	16542	4848	21895
48,4,16-16	2671	2671	201	16546	4849	21889
36,0,4-4	2721	2721	204	16442	4818	21884
40,4,16-16	2726	2726	205	16424	4813	21875
32,16,16-16	2927	2927	218	16011	4692	21866
48,16,16-16	2780	2780	208	16301	4778	21862
40,16,4-4	2851	2851	213	16152	4733	21855
48,8,8-8	2703	2703	203	16444	4819	21851
56,16,8-8	2733	2733	205	16380	4801	21846
32,16,12-12	2925	2925	218	15992	4686	21841
48,4,00	2684	2684	202	16469	4826	21837
36,0,12-12	2712	2712	204	16408	4809	21832
32,16,8-8	2924	2924	218	15979	4683	21827
40,0,00	2692	2692	203	16438	4817	21821
60,12,8-8	2676	2676	202	16465	4825	21817
40,4,8-8	2723	2723	205	16366	4796	21812
52,8,8-8	2676	2676	202	16456	4822	21808
40,0,4-4	2680	2680	201	16443	4819	21803
40,0,8-8	2675	2675	201	16449	4820	21799
60,16,16-16	2697	2697	202	16400	4807	21795

SINGLE 31 BY 7 FEET WINDOW						
Depth - Heigh - Edges	**Central Cooling Coil Load**	**Central Cooling Eqpt Load**	**Central Unit Cooling Input**	**Central Heating Coil Load**	**Central Heating Coil Input**	**TOTAL LOAD**
inch	**(kBTU)**	**(kBTU)**	**(kWh)**	**(kBTU)**	**(kWh)**	**(kBTU)**
40,16,8-8	2842	2842	212	16104	4719	21787
52,16,12-12	2744	2744	206	16294	4776	21782
44,16,12-12	2810	2810	210	16156	4735	21777
48,8,4-4	2700	2700	202	16372	4798	21771
40,0,16-16	2669	2669	200	16428	4815	21766
52,16,16-16	2740	2740	206	16280	4771	21760
60,12,00	2680	2680	201	16396	4806	21756
40,16,12-12	2835	2835	212	16081	4713	21751
40,0,12-12	2668	2668	201	16407	4808	21743
48,4,4-4	2668	2668	201	16399	4806	21736
48,8,16-16	2686	2686	202	16359	4795	21732
44,16,00	2820	2820	211	16087	4715	21727
40,16,00	2841	2841	213	16040	4701	21722
60,16,8-8	2698	2698	203	16320	4783	21716
40,12,16-16	2788	2788	208	16133	4728	21709
44,16,16-16	2800	2800	209	16101	4719	21702
44,16,8-8	2805	2805	210	16087	4715	21698
48,8,00	2699	2699	203	16296	4775	21694
40,12,12-12	2789	2789	209	16111	4722	21689
40,12,8-8	2791	2791	209	16103	4720	21685
44,4,8-8	2673	2673	201	16334	4787	21680
48,8,12-12	2682	2682	202	16311	4781	21675
44,4,12-12	2671	2671	201	16326	4785	21668
44,4,00	2683	2683	202	16296	4776	21662
60,16,4-4	2697	2697	203	16261	4766	21654
60,16,12-12	2686	2686	202	16276	4769	21649
44,4,16-16	2667	2667	200	16311	4780	21644
44,16,4-4	2801	2801	210	16037	4700	21639
44,4,4-4	2676	2676	201	16276	4770	21628
40,16,16-16	2820	2820	211	15981	4684	21621
56,12,00	2682	2682	201	16247	4762	21611
60,16,00	2700	2700	202	16204	4749	21603
52,8,00	2671	2671	201	16255	4764	21597
56,12,12-12	2665	2665	200	16248	4761	21578

40,12,4-4	2787	2787	209	15996	4688	21571
52,8,4-4	2664	2664	200	16227	4755	21555
56,12,16-16	2661	2661	200	16227	4755	21548
56,12,8-8	2666	2666	200	16196	4747	21529
56,12,4-4	2672	2672	201	16176	4741	21520
					MIN	21520
					MAX	24943

– APPENDIX D –

Detailed Report of the Whole-Building Analysis Input Data.

D.1 Entire Arco School Input Data

1. General Details:

Building Name .... **Entire Arco School**

2. Plants Included in this Building:

Plant Name
Arco heating plant

3. Air Systems Included in this Building:

System Name	Mult.
East thermal block	1
North thermal block	1
South thermal block	1
West thermal block	1

4: Miscellaneous Energy

Name	Process Load	Energy/Fuel Type	Peak Use	Schedule
Process energy	Yes	Electric	12.3 kW	Arco school
Service water heater	No	Natural Gas	273.0 MBH	Arco school classroom
Elevator	Yes	Electric	5.0 kW	Arco school
Exterior lighting	No	Electric	1.0 kW	Exterior lighting
Receptacle load	Yes	Electric	21.0 kW	Arco school classroom

5: Meters

Electric .... **Arco electric**

Natural Gas .... **Arco natural gas**

6: Miscellaneous Data

Average Building Power Factor .... **100.00 %**

Source Electric Generating Efficiency .... **28.00 %**

Additional Floor Area **28426.0 ft2**

D.2 Arco Heating Plant Input Data

1. General Details:

Plant Name .... **Arco heating plant**

Plant Type .... **Hot Water Boiler Plant**

2. Air Systems served by Plant:

Air System Name	Mult.
East thermal block	1
North thermal block	1
South thermal block	1
West thermal block	1

3. Configuration

Boiler Sizing .... **User-Specified Boiler Capacity**

Boiler Name .... **Arco heating boiler**

Est. Max Load .... **192.3** MBH

Full Load Capacity .... **493.0** MBH

Hot Water Flow Rate .... **20.0** F°

4. Distribution

Distribution System

Type **Primary/Secondary, Variable Speed Secondary**

Coil Delta-T at Design .... **20.0** F°

Pipe Heat Loss Factor .... **0.0** %

Pump Performance .... **ft wg**

Fluid Properties

Name .... **Fresh Water**

Density **60.6** lb/ft3

Specific Heat .... **1.00** BTU / (lb - F°)

Primary Loop

Pump for...	**Flow**	**Head (ft wg)**	**Mechanical Efficiency (%)**	**Electrical Efficiency (%)**
B-1	20.0 F°	15.0	80.0	94.0

Secondary Loop

	Flow	**Head (ft wg)**	**Mechanical Efficiency (%)**	**Electrical Efficiency (%)**
Design	20.0 F°	20.0	80.0	94.0

Control Head .... **0.0** ft wg

Minimum Pump Flow .... **100.0** %

D.3 East Thermal Block Input Data

1. General Details:

Air System Name .... **East thermal block**

Equipment Type .... **Split AHU**

Air System Type .... **CAV with Terminal Reheat**

Number of zones **1**

2. System Components:

Ventilation Air Data:

Airflow Control .... **Scheduled control**

Ventilation Sizing Method .... **ASHRAE Std 62-2001**

Schedule .... **Arco school classroom**

Damper Leak Rate .... **0** %

Outdoor Air CO2 Level .... **400** ppm

Economizer Data:

Control .... **Integrated enthalpy control**

Upper Cutoff .... **73.0** F°

Lower Cutoff .... **-60.0** F°

Ventilation Reclaim Data:

Reclaim Type .... **Sensible Heat**

Thermal Efficiency .... **90** %

Input kW .... **0.000** kW

Schedule .... **JFMAMJJASOND**

Central Cooling Data:

Supply Air Temperature .... **55.0** F°

Coil Bypass Factor **0.100**

Cooling Source .... **Air-Cooled DX**

Schedule .... **JFMAMJJASOND**

Capacity Control **Temperature Reset by Greatest Zone Demand**

Max. Supply Temperature .... **65.0** F°

Supply Fan Data:

Fan Type .... **Forward Curved**

Configuration .... **Draw-thru**

Fan Performance .... **1.00** in wg

Overall Efficiency .... **54** %

Duct System Data:

Supply Duct Data:

Duct Heat Gain .... **0** %

Duct Leakage .... **0** %

Return Duct or Plenum Data:

Return Air Via .... **Ducted Return**

3. Zone Components:

Space Assignments:

Zone 1: Zone 1	
2-07 Classroom	x1
2-08 Classroom	x1
2nd floor toilet rooms	x1
3-10 Physics Lab	x1

3-11 Storage	x1
3-12 Music Room	x1
3rd floor toilet room	x1
4-07 Physics Lab	x1
4-08 Storage	x1
4-09 Classroom	x1

Thermostats and Zone Data:

Zone .... **All**

Cooling T-stat: Occ. .... **75.0** F°

Cooling T-stat: Unocc. .... **85.0** F°

Heating T-stat: Occ. .... **70.0** F°

Heating T-stat: Unocc. .... **60.0** F°

T-stat Throttling Range .... **3.00** F°

Diversity Factor .... **100** %

Direct Exhaust Airflow .... **0.0** CFM

Direct Exhaust Fan kW .... **0.0** kW

Thermostat Schedule .... **Arco equipment thermostat**

Unoccupied Cooling is .... **Available**

Supply Terminals Data:

Zone .... **All**

Terminal Type .... **Diffuser**

Minimum Airflow .... **0.00** CFM/person

Zone Heating Units:

Zone .... **All**

Zone Heating Unit Type **Baseboard, room T-stat control**

Zone Unit Heat Source .... **Hot Water**

Zone Heating Unit Schedule .... **JFMAMJJASOND**

4. Sizing Data (Computer-Generated):

System Sizing Data:

Cooling Supply Temperature .... **55.0** F°

Supply Fan Airflow .... **2644.2** CFM

Ventilation Airflow .... **2644.2** CFM

Hydronic Sizing Specifications:

Chilled Water Delta-T .... **10.0** F°

Hot Water Delta-T .... **20.0** F°

Safety Factors:

Cooling Sensible .... **0** %

Cooling Latent .... **0** %

Heating .... **0** %

Zone Sizing Data:

Zone Airflow Sizing Method **Sum of space airflow rates**

Space Airflow Sizing Method **Individual peak space loads**

Zone	Supply Airflow (CFM)	Zone Htg Unit (MBH)	Reheat Coil (MBH)	- (CFM)
1	2644.2	57.5	-	

5. Equipment Data

Central Cooling Unit - Air-Cooled DX

Estimated Maximum Load .... **117.7** MBH

Design OAT .... **95.0** F°

Equipment Sizing .... **Auto-Sized**

Capacity Oversizing Factor .... **0.0** %

ARI Performance Rating .... **15.00** EER

Conventional Cutoff OAT .... **55.0** F°

Low Temperature Operation .... **Used**

Low Temperature Cutoff OAT .... **0.0** F°

D.4 West Thermal Block Input Data

1. General Details:

Air System Name .... **West thermal block**

Equipment Type .... **Split AHU**

Air System Type .... **CAV with Terminal Reheat**

Number of zones **1**

2. System Components:

Ventilation Air Data:

Airflow Control .... **Scheduled control**

Ventilation Sizing Method .... **ASHRAE Std 62-2001**

Schedule .... **Arco school classroom**

Damper Leak Rate .... **0** %

Outdoor Air CO2 Level .... **400** ppm

Economizer Data:

Control .... **Integrated enthalpy control**

Upper Cutoff .... **73.0** F°

Lower Cutoff .... **-60.0** F°

Ventilation Reclaim Data:

Reclaim Type .... **Sensible Heat**

Thermal Efficiency .... **90** %

Input kW .... **0.000** kW

Schedule .... **JFMAMJJASOND**

Central Cooling Data:

Supply Air Temperature .... **55.0** F°

Coil Bypass Factor **0.100**

Cooling Source .... **Air-Cooled DX**

Schedule .... **JFMAMJJASOND**

Capacity Control **Temperature Reset by Greatest Zone Demand**

Max. Supply Temperature .... **65.0** F°

Supply Fan Data:

Fan Type .... **Forward Curved**

Configuration .... **Draw-thru**

Fan Performance .... **1.00** in wg

Overall Efficiency .... **54** %

Duct System Data:

Supply Duct Data:

Duct Heat Gain .... **0** %

Duct Leakage .... **0** %

Return Duct or Plenum Data:

Return Air Via .... **Ducted Return**

3. Zone Components:

Space Assignments:

Zone 1: Zone 1	
2-03 Classroom	x1
2-04 Classroom	x1
3-02 Secretary office	x1
3-03 3-04 toilets	x1
3-06 Porters lodge	x1
3-07 Teachers-Library	x1
4-01 Classroom	x1
4-02 Storage	x1
4-03 Classroom	x1
Refectory	x1

Thermostats and Zone Data:

Zone .... **All**

Cooling T-stat: Occ. .... **75.0** F°

Cooling T-stat: Unocc. .... **85.0** F°

Heating T-stat: Occ. .... **70.0** F°

Heating T-stat: Unocc. .... **60.0** F°

T-stat Throttling Range .... **3.00** F°

Diversity Factor .... **100** %

Direct Exhaust Airflow .... **0.0** CFM

Direct Exhaust Fan kW .... **0.0** kW

Thermostat Schedule .... **Arco equipment thermostat**

Unoccupied Cooling is .... **Available**

Supply Terminals Data:

Zone .... **All**

Terminal Type .... **Diffuser**

Minimum Airflow .... **0.00** CFM/person

Zone Heating Units:

Zone .... **All**

Zone Heating Unit Type **Baseboard, room T-stat control**

Zone Unit Heat Source .... **Hot Water**

Zone Heating Unit Schedule .... **JFMAMJJASOND**

4. Sizing Data (Computer-Generated):

System Sizing Data:

Cooling Supply Temperature .... **55.0** F°

Supply Fan Airflow .... **5370.9** CFM

Ventilation Airflow .... **5370.9** CFM

Hydronic Sizing Specifications:

Chilled Water Delta-T .... **10.0** F°

Hot Water Delta-T .... **20.0** F°

Safety Factors:

Cooling Sensible .... **0** %

Cooling Latent .... **0** %

Heating .... **0** %

Zone Sizing Data:

Zone Airflow Sizing Method **Sum of space airflow rates**

Space Airflow Sizing Method **Individual peak space loads**

Zone	Supply Airflow (CFM)	Zone Htg Unit (MBH)	Reheat Coil (MBH)	- (CFM)
1	5370.9	114.1	-	

5. Equipment Data

Central Cooling Unit - Air-Cooled DX

Estimated Maximum Load .... **153.7** MBH

Design OAT .... **95.0** F°

Equipment Sizing .... **Auto-Sized**

Capacity Oversizing Factor .... **0.0** %

ARI Performance Rating .... **15.00** EER

Conventional Cutoff OAT .... **55.0** F°

Low Temperature Operation .... **Used**

Low Temperature Cutoff OAT .... **9.0** F°

D.5 North Thermal Block Input Data

1. General Details:

Air System Name .... **North thermal block**

Equipment Type .... **Split AHU**

Air System Type .... **CAV with Terminal Reheat**

Number of zones **1**

2. System Components:

Ventilation Air Data:

Airflow Control .... **Scheduled control**

Ventilation Sizing Method .... **ASHRAE Std 62-2001**

Schedule .... **Arco school classroom**

Damper Leak Rate .... **0** %

Outdoor Air CO2 Level .... **400** ppm

Economizer Data:

Control .... **Integrated enthalpy control**

Upper Cutoff .... **73.0** F°

Lower Cutoff .... **-60.0** F°

Ventilation Reclaim Data:

Reclaim Type .... **Sensible Heat**

Thermal Efficiency .... **90** %

Input kW .... **0.000** kW

Schedule .... **JFMAMJJASOND**

Central Cooling Data:

Supply Air Temperature .... **55.0** F°

Coil Bypass Factor **0.100**

Cooling Source .... **Air-Cooled DX**

Schedule .... **JFMAMJJASOND**

Capacity Control **Temperature Reset by Greatest Zone Demand**

Max. Supply Temperature .... **65.0** F°

Supply Fan Data:

Fan Type .... **Forward Curved**

Configuration .... **Draw-thru**

Fan Performance .... **1.00** in wg

Overall Efficiency .... 54 %

Duct System Data:

Supply Duct Data:

Duct Heat Gain .... 0 %

Duct Leakage .... 0 %

Return Duct or Plenum Data:

Return Air Via .... **Ducted Return**

3. Zone Components:

Space Assignments:

Zone 1: Zone 1	
4-16 Classroom	x1
4th floor toilet room	x1
Core-Atrium	x1

Thermostats and Zone Data:

Zone .... **All**

Cooling T-stat: Occ. .... **75.0** F°

Cooling T-stat: Unocc. .... **85.0** F°

Heating T-stat: Occ. .... **70.0** F°

Heating T-stat: Unocc. .... **60.0** F°

T-stat Throttling Range .... **3.00** F°

Diversity Factor .... **100** %

Direct Exhaust Airflow .... **0.0** CFM

Direct Exhaust Fan kW .... **0.0** kW

Thermostat Schedule .... **Arco equipment thermostat**

Unoccupied Cooling is .... **Available**

Supply Terminals Data:

Zone .... **All**

Terminal Type .... **Diffuser**

Minimum Airflow .... **0.00** CFM/person

Zone Heating Units:

Zone .... **All**

Zone Heating Unit Type **Baseboard, room T-stat control**

Zone Unit Heat Source .... **Hot Water**

Zone Heating Unit Schedule .... **JFMAMJJASOND**

4. Sizing Data (Computer-Generated):

System Sizing Data:

Cooling Supply Temperature .... **55.0** F°

Supply Fan Airflow .... **1829.7** CFM

Ventilation Airflow .... **1074.6** CFM

Hydronic Sizing Specifications:

Chilled Water Delta-T .... **10.0** F°

Hot Water Delta-T .... **20.0** F°

Safety Factors:

Cooling Sensible .... **0** %

Cooling Latent .... **0** %

Heating .... **0** %

Zone Sizing Data:

Zone Airflow Sizing Method **Sum of space airflow rates**

Space Airflow Sizing Method **Individual peak space loads**

Zone	Supply Airflow (CFM)	Zone Htg Unit (MBH)	Reheat Coil (MBH)	- (CFM)
1	1829.7	45.4	-	

D.6 South Thermal Block Input Data

1. General Details:

Air System Name .... **South thermal block**

Equipment Type .... **Split AHU**

Air System Type .... **CAV with Terminal Reheat**

Number of zones **1**

2. System Components:

Ventilation Air Data:

Airflow Control .... **Scheduled control**

Ventilation Sizing Method .... **ASHRAE Std 62-2001**

Schedule .... **Arco school classroom**

Damper Leak Rate .... **0** %

Outdoor Air CO2 Level .... **400** ppm

Economizer Data:

Control .... **Integrated enthalpy control**

Upper Cutoff .... **73.0** F°

Lower Cutoff .... **-60.0** F°

Ventilation Reclaim Data:

Reclaim Type .... **Sensible Heat**

Thermal Efficiency .... **90** %

Input kW .... **0.000** kW

Schedule .... **JFMAMJJASOND**

Central Cooling Data:

Supply Air Temperature .... **55.0** F°

Coil Bypass Factor **0.100**

Cooling Source .... **Air-Cooled DX**

Schedule .... **JFMAMJJASOND**

Capacity Control **Temperature Reset by Greatest Zone Demand**

Max. Supply Temperature .... **65.0** F°

Supply Fan Data:

Fan Type .... **Forward Curved**

Configuration .... **Draw-thru**

Fan Performance .... **1.00** in wg

Overall Efficiency .... **54** %

Duct System Data:

Supply Duct Data:

Duct Heat Gain .... 0 %

Duct Leakage .... 0 . %

Return Duct or Plenum Data:

Return Air Via .... **Ducted Return**

3. Zone Components:

Space Assignments:

Zone 1: Zone 1	
2-05 Classroom	x1
2-06 Classroom	x1
3-08 Classroom	x1
3-09 Language Lab	x1
4-04 Classroom	x1
4-05 Storage	x1
4-06 Language Lab	x1
Gymnasium	x1
Locker room	x1
South Filter (stairwell)	x1

Thermostats and Zone Data:

Zone .... **All**

Cooling T-stat: Occ. .... **75.0** F°

Cooling T-stat: Unocc. .... **85.0** F°

Heating T-stat: Occ. .... **70.0** F°

Heating T-stat: Unocc. .... **60.0** F°

T-stat Throttling Range .... **3.00** F°

Diversity Factor .... **100** %

Direct Exhaust Airflow .... **0.0** CFM

Direct Exhaust Fan kW .... **0.0** kW

Thermostat Schedule .... **Arco equipment thermostat**

Unoccupied Cooling is .... **Available**

Supply Terminals Data:

Zone .... **All**

Terminal Type .... **Diffuser**

Minimum Airflow .... **0.00** CFM/person

Zone Heating Units:

Zone .... **All**

Zone Heating Unit Type **Baseboard, room T-stat control**

Zone Unit Heat Source .... **Hot Water**

Zone Heating Unit Schedule .... **JFMAMJJASOND**

4. Sizing Data (Computer-Generated):

System Sizing Data:

Cooling Supply Temperature .... **55.0** F°

Supply Fan Airflow .... **5400.6** CFM

Ventilation Airflow .... **3066.8** CFM

Hydronic Sizing Specifications:

Chilled Water Delta-T .... **10.0** F°

Hot Water Delta-T .... **20.0** F°

Safety Factors:

Cooling Sensible .... **0** %

Cooling Latent .... **0** %

Heating .... **0** %

Zone Sizing Data:

Zone Airflow Sizing Method **Sum of space airflow rates**

Space Airflow Sizing Method **Individual peak space loads**

Zone	Supply Airflow (CFM)	Zone Htg Unit (MBH)	Reheat Coil (MBH)	- (CFM)
1	5400.6	157.5	-	

5. Equipment Data

Central Cooling Unit - Air-Cooled DX

Estimated Maximum Load .... **195.9** MBH

Design OAT .... **95.0** F°

Equipment Sizing .... **Auto-Sized**

Capacity Oversizing Factor .... **0.0** %

ARI Performance Rating .... **15.00** EER

Conventional Cutoff OAT .... **55.0** F°

Low Temperature Operation .... **Used**

Low Temperature Cutoff OAT .... **0.0** F°

– APPENDIX E –

Whole-Building Analysis Results: Multiple Geographical Locations.

E.1 Location # 1: Naples – Italy.

NAPLES – DESIGN CASE RESULTS

Table 1.
Annual Costs

Component	Entire Arco school shading ($)
HVAC Components	
Electric	6,710
Natural Gas	3,419
HVAC Sub-Total	**10,129**
Non-HVAC Components	
Electric	26,492
Natural Gas	8,479
Non-HVAC Sub-Total	**34,971**
Grand Total	**45,100**

Table 2.
Annual Energy Consumption

Component	Entire Arco school shading ($)
HVAC Components	
Electric (kWh)	23,682
Natural Gas (Therm)	1,671
Non-HVAC Components	
Electric (kWh)	93,499
Natural Gas (Therm)	4,144
Totals	
Electric (kWh)	117,181
Natural Gas (Therm)	5,814

NAPLES – BASELINE CASE

Table 1.
Annual Costs

Component	Entire Arco school shading ($)
HVAC Components	
Electric	7,654
Natural Gas	3,424
HVAC Sub-Total	**11,078**
Non-HVAC Components	
Electric	26,492
Natural Gas	8,479
Non-HVAC Sub-Total	**34,971**
Grand Total	**46,049**

Table 2.
Annual Energy Consumption

Component	Entire Arco school shading ($)
HVAC Components	
Electric (kWh)	27,015
Natural Gas (Therm)	1,673
Non-HVAC Components	
Electric (kWh)	93,499
Natural Gas (Therm)	4,144
Totals	
Electric (kWh)	120,514
Natural Gas (Therm)	5,817

NAPLES – DESIGN CASE RESULTS

Table 3.
Annual Cost per Unit Floor Area

Component	Entire Arco school shading ($)
HVAC Components	
Electric	0.108
Natural Gas	0.055
HVAC Sub-Total	**0.163**
Non-HVAC Components	
Electric	0.426
Natural Gas	0.136
Non-HVAC Sub-Total	**0.562**
Grand Total	**0.725**
Gross Floor Area (ft^2)	62227.5
Conditioned Floor Area (ft^2)	33801.5

Table 4.
Component Cost as a Percentage of Total Cost

Component	Entire Arco school shading ($)
HVAC Components	
Electric	14.9
Natural Gas	7.6
HVAC Sub-Total	**22.5**
Non-HVAC Components	
Electric	58.7
Natural Gas	18.8
Non-HVAC Sub-Total	**77.5**
Grand Total	**100**

NAPLES – BASELINE CASE

Table 3.
Annual Cost per Unit Floor Area

Component	Entire Arco school shading ($)
HVAC Components	
Electric	0.123
Natural Gas	0.055
HVAC Sub-Total	**0.178**
Non-HVAC Components	
Electric	0.426
Natural Gas	0.136
Non-HVAC Sub-Total	**0.562**
Grand Total	**0.74**
Gross Floor Area (ft^2)	62227.5
Conditioned Floor Area (ft^2)	33801.5

Table 4.
Component Cost as a Percentage of Total Cost

Component	Entire Arco school shading ($)
HVAC Components	
Electric	16.6
Natural Gas	7.4
HVAC Sub-Total	**24.1**
Non-HVAC Components	
Electric	57.5
Natural Gas	18.4
Non-HVAC Sub-Total	**75.9**
Grand Total	**100**

E.2 Location # 2: Valencia – Spain.

VALENCIA – DESIGN CASE RESULTS

Table 1.
Annual Costs

Component	Entire Arco school shading ($)
HVAC Components	
Electric	6,678
Natural Gas	3,402
HVAC Sub-Total	**10,080**
Non-HVAC Components	
Electric	26,492
Natural Gas	8,479
Non-HVAC Sub-Total	**34,971**
Grand Total	**45,051**

Table 2.
Annual Energy Consumption

Component	Entire Arco school shading ($)
HVAC Components	
Electric (kWh)	23,569
Natural Gas (Therm)	1,662
Non-HVAC Components	
Electric (kWh)	93,499
Natural Gas (Therm)	4,144
Totals	
Electric (kWh)	117,068
Natural Gas (Therm)	5,806

VALENCIA – BASELINE CASE

Table 1.
Annual Costs

Component	Entire Arco school shading ($)
HVAC Components	
Electric	7,619
Natural Gas	3,414
HVAC Sub-Total	**11,033**
Non-HVAC Components	
Electric	26,492
Natural Gas	8,479
Non-HVAC Sub-Total	**34,971**
Grand Total	**46,004**

Table 2.
Annual Energy Consumption

Component	Entire Arco school shading ($)
HVAC Components	
Electric (kWh)	26,889
Natural Gas (Therm)	1,668
Non-HVAC Components	
Electric (kWh)	93,499
Natural Gas (Therm)	4,144
Totals	
Electric (kWh)	120,388
Natural Gas (Therm)	5,812

VALENCIA – DESIGN CASE RESULTS

Table 3.
Annual Cost per Unit Floor Area

Component	Entire Arco school shading ($)
HVAC Components	
Electric	0.107
Natural Gas	0.055
HVAC Sub-Total	**0.162**
Non-HVAC Components	
Electric	0.426
Natural Gas	0.136
Non-HVAC Sub-Total	**0.562**
Grand Total	**0.724**
Gross Floor Area (ft²)	62227.5
Conditioned Floor Area (ft²)	33801.5

Table 4.
Component Cost as a Percentage of Total Cost

Component	Entire Arco school shading ($)
HVAC Components	
Electric	14.8
Natural Gas	7.6
HVAC Sub-Total	**22.4**
Non-HVAC Components	
Electric	58.8
Natural Gas	18.8
Non-HVAC Sub-Total	**77.6**
Grand Total	**100**

VALENCIA – BASELINE CASE

Table 3.
Annual Cost per Unit Floor Area

Component	Entire Arco school shading ($)
HVAC Components	
Electric	0.122
Natural Gas	0.055
HVAC Sub-Total	**0.177**
Non-HVAC Components	
Electric	0.426
Natural Gas	0.136
Non-HVAC Sub-Total	**0.562**
Grand Total	**0.739**
Gross Floor Area (ft²)	62227.5
Conditioned Floor Area (ft²)	33801.5

Table 4.
Component Cost as a Percentage of Total Cost

Component	Entire Arco school shading ($)
HVAC Components	
Electric	16.6
Natural Gas	7.4
HVAC Sub-Total	**24**
Non-HVAC Components	
Electric	57.6
Natural Gas	18.4
Non-HVAC Sub-Total	**76**
Grand Total	**100**

E.3 Location # 3: Frankfurt – Germany.

FRANKFURT – DESIGN CASE RESULTS

Table 1.
Annual Costs

Component	Entire Arco school shading ($)
HVAC Components	
Electric	6,437
Natural Gas	3,446
HVAC Sub-Total	**9,884**
Non-HVAC Components	
Electric	26,492
Natural Gas	8,479
Non-HVAC Sub-Total	**34,971**
Grand Total	**44,855**

Table 2.
Annual Energy Consumption

Component	Entire Arco school shading ($)
HVAC Components	
Electric (kWh)	22,719
Natural Gas (Therm)	1,684
Non-HVAC Components	
Electric (kWh)	93,499
Natural Gas (Therm)	4,144
Totals	
Electric (kWh)	116,218
Natural Gas (Therm)	5,828

FRANKFURT– BASELINE CASE

Table 1.
Annual Costs

Component	Entire Arco school shading ($)
HVAC Components	
Electric	7,336
Natural Gas	3,425
HVAC Sub-Total	**10,761**
Non-HVAC Components	
Electric	26,492
Natural Gas	8,479
Non-HVAC Sub-Total	**34,971**
Grand Total	**45,732**

Table 2.
Annual Energy Consumption

Component	Entire Arco school shading ($)
HVAC Components	
Electric (kWh)	25,892
Natural Gas (Therm)	1,673
Non-HVAC Components	
Electric (kWh)	93,499
Natural Gas (Therm)	4,144
Totals	
Electric (kWh)	119,391
Natural Gas (Therm)	5,817

FRANKFURT – DESIGN CASE RESULTS

Table 3.
Annual Cost per Unit Floor Area

Component	Entire Arco school shading ($)
HVAC Components	
Electric	0.103
Natural Gas	0.055
HVAC Sub-Total	**0.159**
Non-HVAC Components	
Electric	0.426
Natural Gas	0.136
Non-HVAC Sub-Total	**0.562**
Grand Total	**0.721**
Gross Floor Area (ft^2)	62227.5
Conditioned Floor Area (ft^2)	33801.5

Table 4.
Component Cost as a Percentage of Total Cost

Component	Entire Arco school shading ($)
HVAC Components	
Electric	14.4
Natural Gas	7.7
HVAC Sub-Total	**22**
Non-HVAC Components	
Electric	59.1
Natural Gas	18.9
Non-HVAC Sub-Total	**78**
Grand Total	**100**

FRANKFURT– BASELINE CASE

Table 3.
Annual Cost per Unit Floor Area

Component	Entire Arco school shading ($)
HVAC Components	
Electric	0.118
Natural Gas	0.055
HVAC Sub-Total	**0.173**
Non-HVAC Components	
Electric	0.426
Natural Gas	0.136
Non-HVAC Sub-Total	**0.562**
Grand Total	**0.735**
Gross Floor Area (ft^2)	62227.5
Conditioned Floor Area (ft^2)	33801.5

Table 4.
Component Cost as a Percentage of Total Cost

Component	Entire Arco school shading ($)
HVAC Components	
Electric	16
Natural Gas	7.5
HVAC Sub-Total	**23.5**
Non-HVAC Components	
Electric	57.9
Natural Gas	18.5
Non-HVAC Sub-Total	**76.5**
Grand Total	**100**

– APPENDIX F –

Additional information related to patented shading devices and existing research.

1. Patented Movable Shading Devices.

- **U.S. Patent no. 4,517,960** – Bartenbach Christian 1983 – is an invention of a protection device against sunlight. The shading device consists of:
  - A plurality of slats that are made of a light-permeable, refracting material. The slats have a flat non-reflective base surface on a side oriented to the sun and a prismatic structure on the opposite side oriented away from the sun, as shown in figure 2.12.
  - The prismatic structure consists of prismatic rods that have a triangular cross section. The prismatic rods are parallel to the longitudinal axes and have two non-reflective surfaces that work only by total internal reflection, as illustrated in figure 2.13.

The slats are arranged in a side-by-side relationship in a window opening. The slats are mechanically coupled to one another, and all the slats are simultaneously moved at the same time and for the same angle around the longitudinal axes (Bartenbach - 04/22/2008).

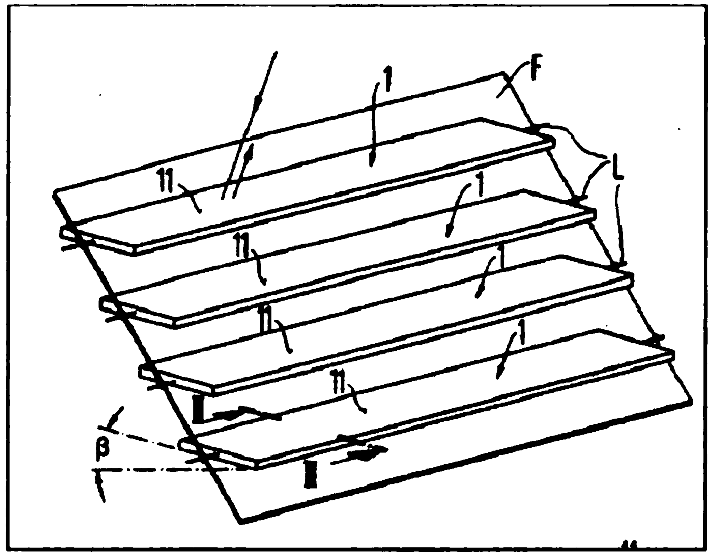

Figure F1: Isometric view of the patent 4,517,960 shading device.

(Bartenbach Christian - 1983)

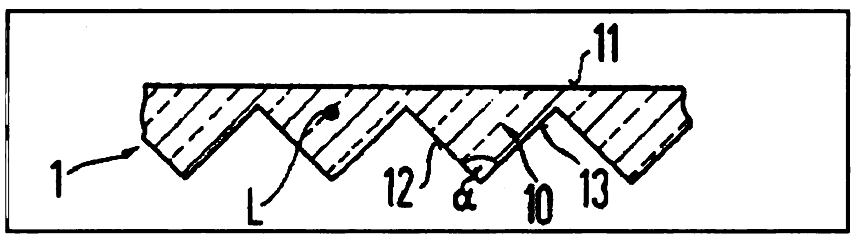

Figure F2: Cross section through the prismatic slat of the patent 4,517,960 shading device

(Bartenbach Christian - 1983).

Inclination of the slats can be changed during he day and year, depending on the angle of the sun rays. This shading device has the following advantages:

- Improved light transmittance.
- Effective protection from the sunlight.

- Does not require adjustment of the slat inclination during the day for the south orientation since the required screening conditions are fulfilled during several days.
- It requires little adjustment throughout the year for the south orientation. For instance, only four adjustments of the angle of inclination of the slats are needed. These four adjustments cover the entire range of change in altitude angle in accordance with the time of year (in meridian plane 47°) with a screening range of 12° in the same plane.

The slats can be adjusted to let sun rays enter the interior space and be used for heating the space in winter. Transparency of the shading device can be improved in two ways:

- By improving the transparency of the obstructed (slat) area or
- Reducing the obstructed (slat) area

Transparency of the obstructed area can be improved by adding another prism array. The slats become transparent since the additional prism restores the direction of the light rays that pass through the slat and are not internally reflected.

- **U.S. Patent no. 3,438,699** - B.I. Seeger 1969 - The shading device consists of multiple slats assembled in a configuration similar to Venetian blinds. The slats can be either horizontal or vertical, and they are collectively moved depending on the sun angle, as shown in figure 2.14. Each slat consists of two prisms which are oriented opposite of each other. Together they form a rectangular cross-sectioned slat, being

0.1707" thick, and 2. wide, and as long as one dimension of a sunlight area as shown in figure 2.15 (Seeger – 22/04/2008).

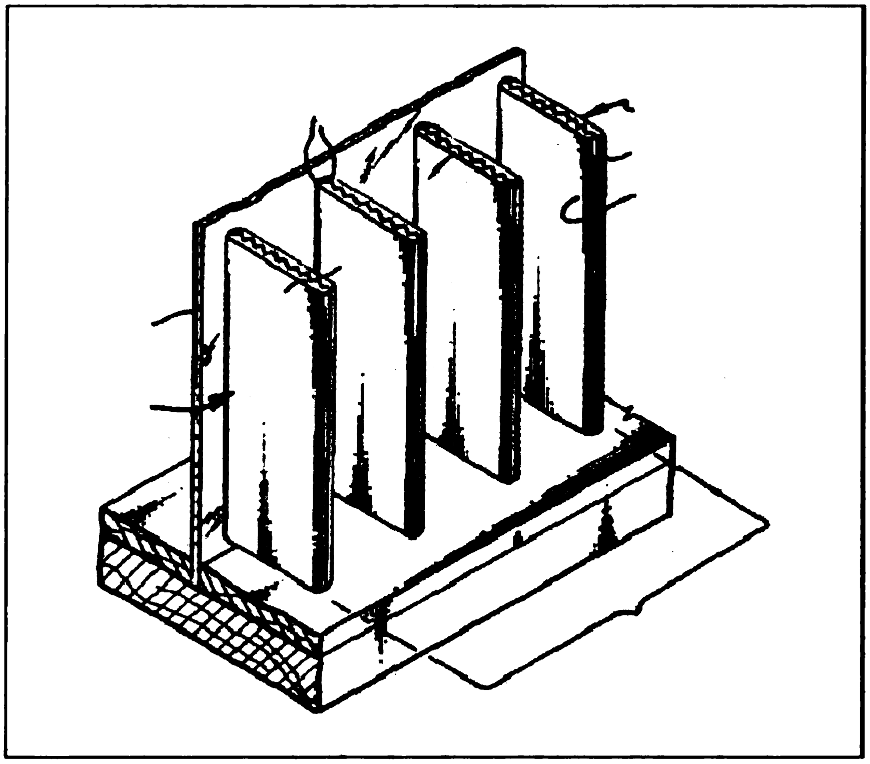

Figure F3: Horizontal section of the patent 3,438,699 prismatic slat (Seeger – 22/04/2008)..

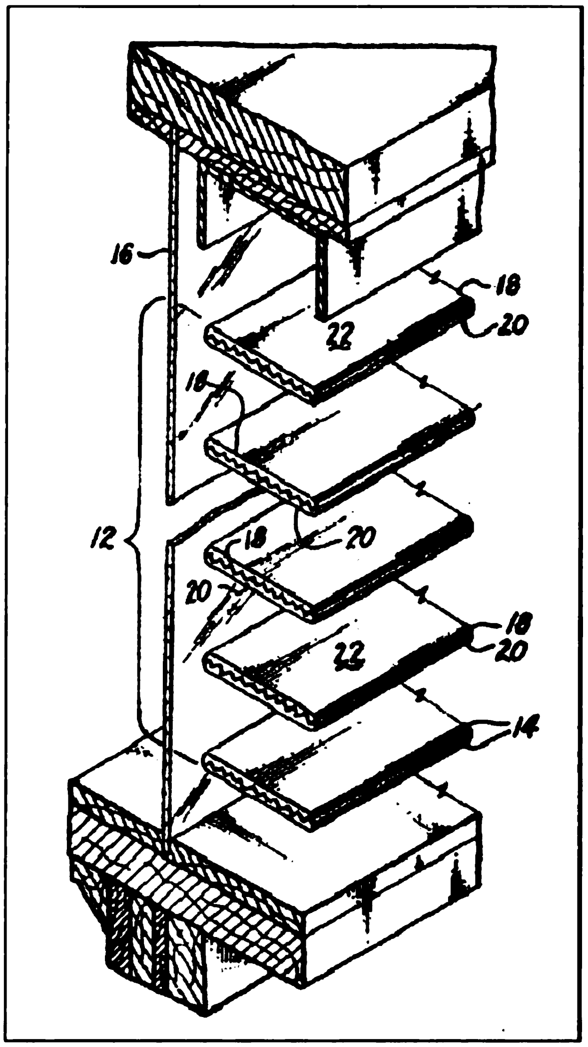

Figure F4: Isometric view of the patent 3,438,699 prismatic shading device.

(Seeger – 22/04/2008)

The ridges of prisms are immersed in a thin medium, such as air or a vacuum, which has an index of refraction lower than the prism material. The materials used for slats are highly transparent to all light, such as a transparent polymethyl methacrylate material, which has an index of refraction 1.49. Figure 2.16 reported below shows a cross section of the prismatic shading device.

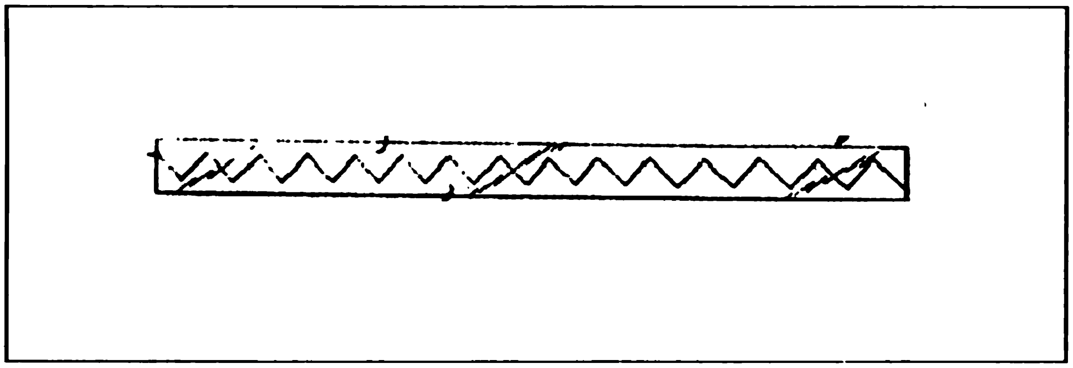

Figure F5: Cross section of the patent 3,438,699 prismatic shading device (Seeger – 22/04/2008).

Refraction and total reflection of the sun rays for different incident angles can be calculated using the sample scheme reported in figure 2.17:

- Ray A has an incident angle 0°, that is, it is perpendicular to the surface, and it will be totally internally reflected, protecting the interior space from overheating and glare.
- Ray B is twice refracted and emerges parallel to its original direction. An occupant has a clear and undistorted view along the line of such a ray. Ray B is not a glare ray and it supplies the desired light to the interior space. Ray B forms a "clear view range."
- Ray C is refracted at the first outside surface and after that there are several successive total internal reflections at the parallel surfaces of the slat. Rays C forms an "opaque view range."

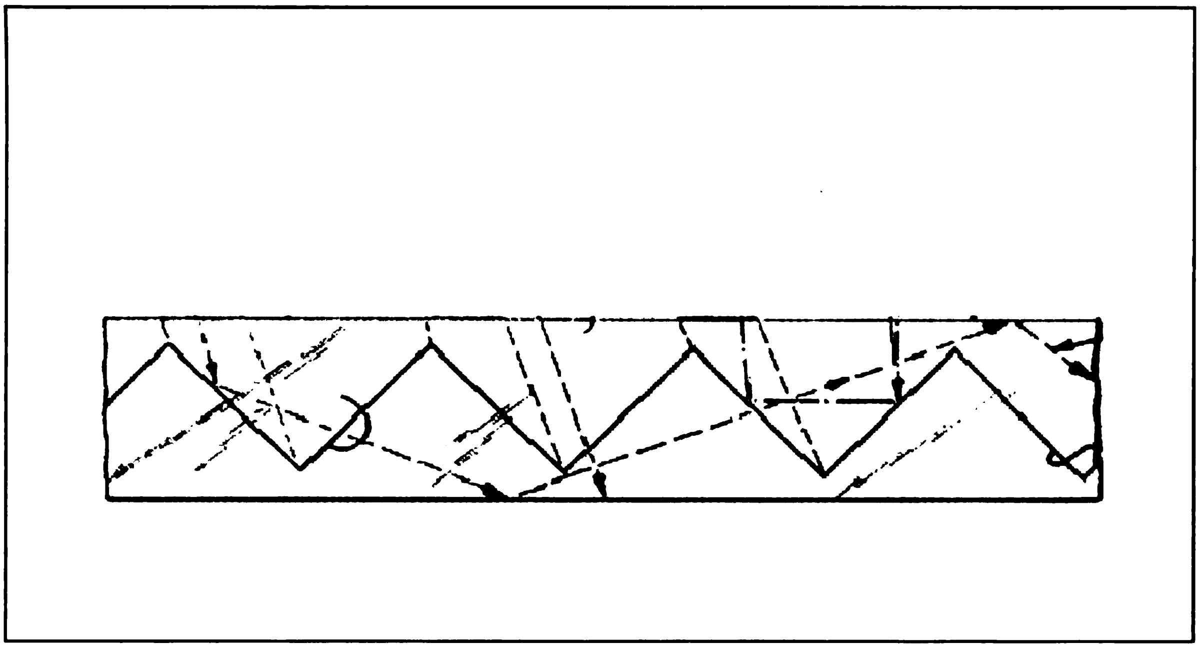

Figure F6: Detailed cross section through the patent 3,438,699 prismatic shading device (Seeger – 22/04/2008).

This shading device totally reflects all glare rays. Indirect glare rays are totally reflected while other light rays that have less energy are provided to the space beyond the location of the slats by:

- Construction of the slats proposed by this invention.
- Using transparent materials with indices of refraction equal to or greater than ã2.
- Control of their collective rotation.

The other strategy for improving the transparency of a shading device is reducing the slat area. A different functional arrangement of the slats is needed for achieving this goal. Assuming a mean solar profile angle between 45° and 60°, only a retro-reflecting slat will provide protection at nearly a horizontal orientation. Figure 2.18 shows a slat with a retro-angle of 45°.

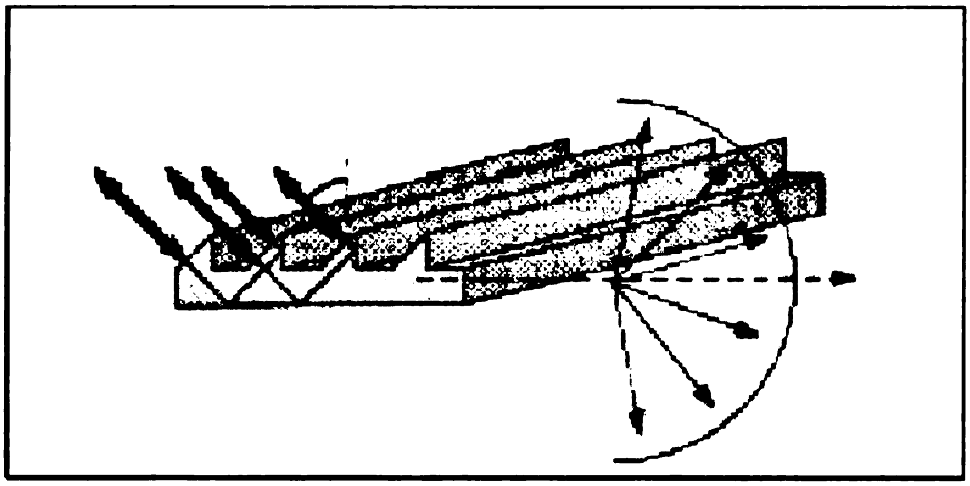

Figure F7: Detailed cross section through the retro/reflecting slat (Seeger – 22/04/2008).

2. Existing Research: "The Light Pipes".

"Light Pipes: Innovative Design Device for Bringing Natural Daylight and Illumination into Buildings with Deep Floor Plan (Patent Applied)" – T.R. Hamzah & Yeang Sdn Bhd Architects – Research work developed for the Asian Innovation Awards 2003.

The innovative device analyzed in this dissertation is the "light-pipe", a passive low-energy device for transmitting natural daylight into buildings with deep plans. The daylight is transmitted horizontally and vertically using internal mirrored surfaced within a box-tube structure (hence the term "pipe") coupled with laser-cut panels (LCP) at the outer edge of the pipe as collectors. In buildings with deep plans (> 10 m from windows), the usual natural illumination from daylight from side windows becomes impossible. Previous studies (Hansen et al. 2001) have shown the potential of mirrored light-pipes in deep-plan buildings, but that light distribution and extraction along the pipe was not optimal. This work developed an optimization of this solution. The main improvement done with this work is relative to the conveyance of solar rays through the use of laser cut panels, represented in figure 2.24.

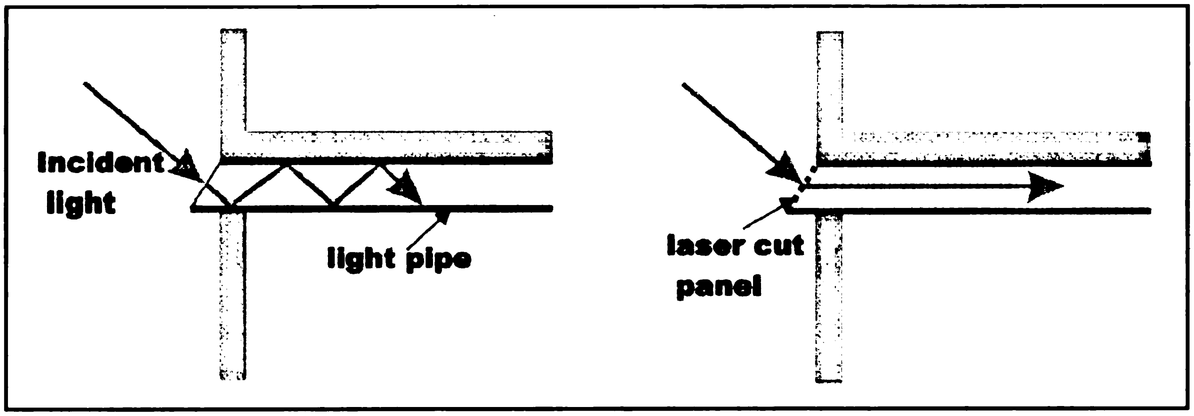

Figure F8: Representation of the Laser Cut Panel effect on the light pipe (Hamzah & Yeang – 2003).

The performance of the light pipes was enhanced with:

- A laser cut panel light deflector at the input aperture to deflect high elevation light more directly along the axis of the pipe, as illustrated in figure 2.25a.
- A light extraction system to extract the required proportion of piped light into the inner zone.
- A light spreading system that distribute the light away from the area directly below the light pipe.

LCPs (Edmonds & All - 1995) were produced by making parallel laser cuts in transparent acrylic panels. Each cut became a thin mirror, which provides powerful deflection of non-perpendicular light. The fraction of light deflected, f_d, depended on the angle of incidence, I, and the cut spacing to cut depth ratio, D/W, as shown in figures 2.25b and 2.25c for three nominal D/W ratios.

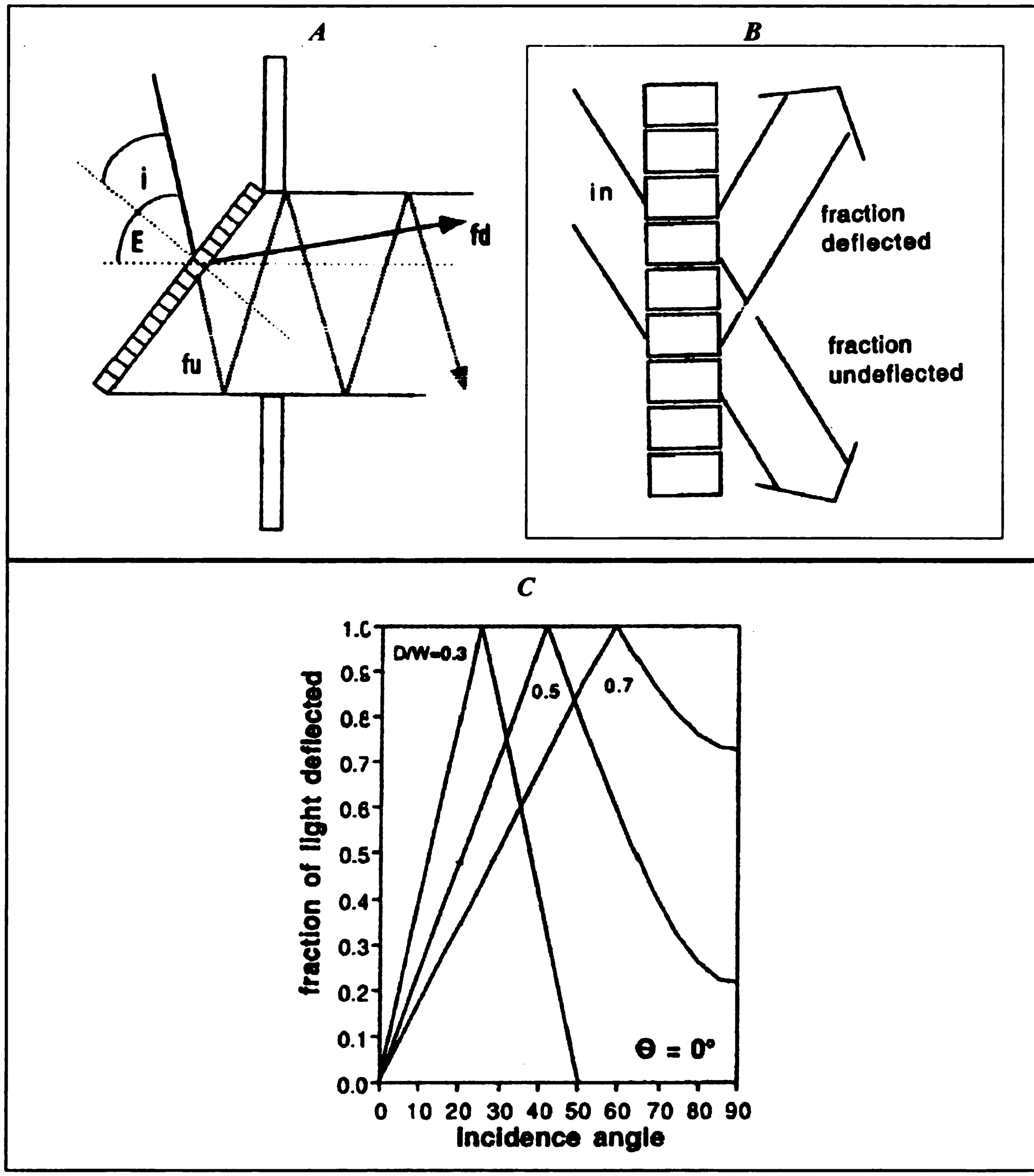

Figure F9: Detail of the Laser Cut Panels function system (Edmonds & All – 1995).

A: light-receiving end of the pipe.

B: Laser cut panel section. Incoming light deflected and transmitted.

C: Fraction of incident light deflected for different spacing to depth ratios (D/W).

This research considered two types of light-pipes, the horizontal and the vertical, and both were analyzed from the practical point of view in a case study in Kuala Lumpur.

Horizontal pipes.

The design used four horizontal light pipes per floor, oriented west-east, with LCP used as light collectors on the west façade. The pipes were 20 m long, 2m wide and 0.8 m high, formed from 85% reflectance material. Each pipe was to illuminate an area of 12 x 12 m. LCP as collectors are inclined at an angle of 55°, which was the optimum angle for a fixed system (in Kuala Lumpur) to redirect sunrays more axially along the pipe, and reduce the number of reflections. This parameter would have been the only one that would had to be re-defined at a practical and structural level because different locations would have been characterized by different latitudes and so different solar light incident angle. Five transparent panels were inserted at a fixed spacing (2 m) along each pipe with sufficient reflectance material to extract approximately one-fifth of the light at each aperture (Edmonds et al. 1997). A triangular arrangement of LCPs was then used to redirect the extracted light sideways to achieve a better and more uniform light distribution over the floor space. Figure 2.26 shows the main element that characterize a horizontal light-pipe system.

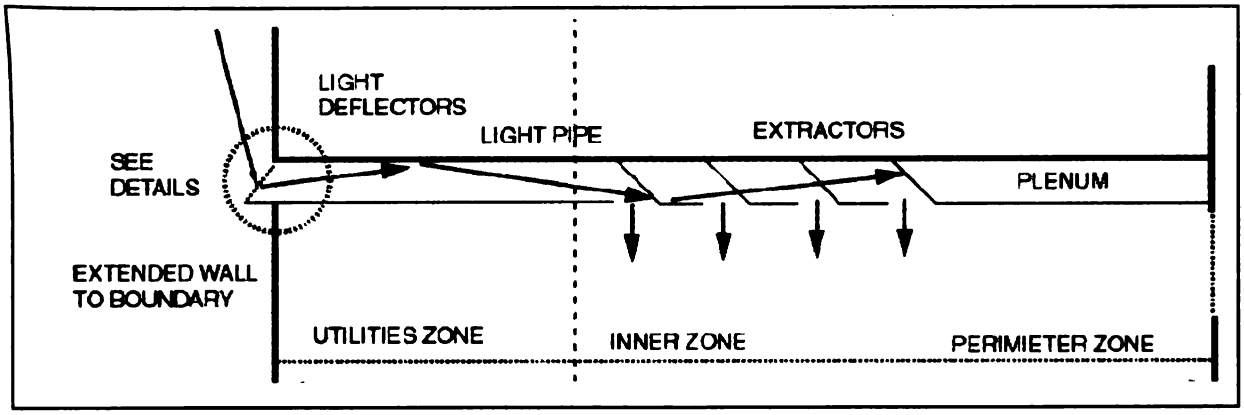

Figure F10: Horizontal light pipe cross-section (Hamzah & Yeang - 2003).

Vertical pipes.

A vertical version was also developed comprising a pyramid form LCP collector to improve the redirection of less the 90° sun angles more axially into a 2 m diameter, 18.4 m long vertical light pipe. The pipe had extraction apertures at each floor. Cone-shaped reflective extractors inclined at 37.5° were placed within the pipe at apertures to redirect the light into the space and illuminate an area of 12 x 12m. A diffusing shelf surrounded each aperture to spread the light upwards and avoid direct view of the aperture by the occupants as schematically shown in figure 2.27.

Researchers considered also other aspects of the light-pipe that could also be implemented in the present research. Its conclusions provided a solid understanding of how these devices could be implemented. For each light-pipe type, the researcher developed some graphic models that represent the different device performances in relationship to the angle of solar light incidence. The initial idea of including light pipes in the simulation model to analyze their possible impact on energy and daylight performance was discarded because of the amount of additional work needed. However, the research was used as reference to define how analysis results could be reported and illustrated. Graphic models ad curves similar to the one reported below were developed in order to link energy performance to shading device variables. For example, figure 2.27 shows Hamzah's graphic result with specific variables (distance from side wall, distance from front wall, lux level).

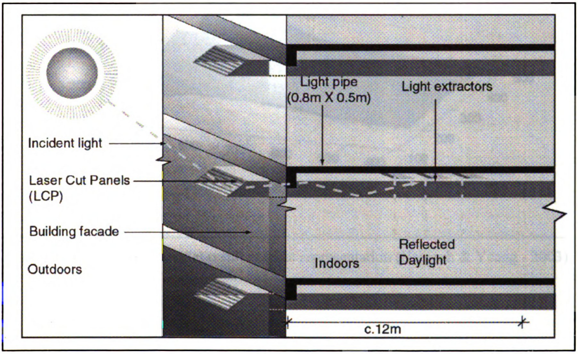

Figure F11: Schematic representation of the vertical light-pipe implementation system (Hamzah & Yeang - 2003).

For comparison between shading device performances and LEED® requirements, such diagrams was intersected with other curves indicating the LEED® minimum requirements. That could give designers an immediate and simple representation of shading device performance impact.

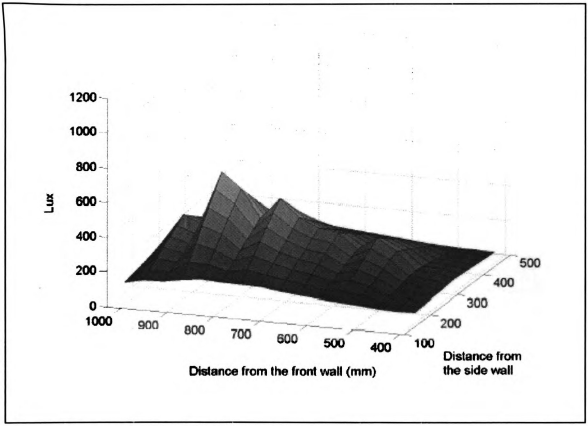

Figure F12: Example of model result graphic representation (Hamzah & Yeang - 2003).

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