Report No. CSS03-07

December 5, 2003

Center for Sustainable Systems
University of Michigan

LEED™ Energy Performance Modeling and Evaluation of the S.T. Dana Building Renovations

Sharada Gundala

LEED™ ENERGY PERFORMANCE MODELING AND EVALUATION OF THE S.T. DANA BUILDING RENOVATIONS

By:

Sharada Gundala

A project submitted in partial fulfillment of requirements
for the degree of Master of Science
(Natural Resources and Environment)

University of Michigan
Ann Arbor

December 05, 2003

Faculty Advisors:
Associate Professor Gregory Keoleian
Professor Thomas Gladwin
Mr. Alan Daly

A report of the Center for Sustainable Systems

Report No. CSS03-07

Document Description

LEED™ ENERGY PERFORMANCE MODELING AND EVALUATION OF THE S.T. DANA BUILDING RENOVATIONS
Sharada Gundala
Center for Sustainable Systems, Report No. CSS03-07
University of Michigan, Ann Arbor, Michigan
December 05, 2003
99 pp., tables, figures, 7 appendices

This document is available online at: http://css.snre.umich.edu

Center for Sustainable Systems
School of Natural Resources and Environment
University of Michigan
440 Church Street, Dana Building
Ann Arbor, MI 48109-1041
Phone: 734-764-1412
Fax: 734-647-5841
Email: css.info@umich.edu
Web: http://css.snre.umich.edu

TABLE OF CONTENTS

ABSTRACT

The University of Michigan's S. T. Dana Building has upgraded its hundred year old infrastructure. The goal of the renovations was a building where the principles of environmental responsibility are not only taught, but upheld and demonstrated to the community. This project is part of a process toward obtaining LEED™ certification for the S.T. Dana Building – Phase II Renovations. The specific objective of this project is to evaluate energy use and the energy efficiency performance of these renovations for LEED™ credits in the Energy & Atmosphere category.

The LEED™ Rating system requires a building energy simulation to demonstrate the energy savings for a proposed project. This report describes the modeling methods and building characteristics and also provides detailed parameters for the simulation. The Phase II renovations are modeled with the eQUEST™ energy analysis software that uses the DOE-2.1 building energy simulation engine. A Base Case model of the Dana Building compliant with ASHRAE 90.1-1999 is developed using eQUEST™ which serves as a baseline reference that meets the minimum energy efficiency requirements for LEED™ certification. A Proposed Case model is developed from the Base Case model with changes that correspond to the efficiency measures implemented in the building renovations. One of the challenges was to model the radiant cooling panels that were added in the non-laboratory spaces in the ground floor through the third floor of the Dana Building. The radiant cooling panels are modeled as a fan-coil unit with infinite fan efficiency to simulate zone cooling, resulting in zero fan energy use.

The model demonstrated that energy savings in the Dana Building are primarily from use of Radiant Cooling Panels. There was a 12% savings in total regulated energy consumption (heating, cooling, fans and pumps, service hot water and interior lighting) and a 20% cost savings, which contributed four LEED™ credit points in the Energy and Atmosphere category. The renovations led to an annual savings of 279,000 kWh of electricity and 586 Mbtu of chilled water. This in turn saved $22,861 and $11,474 for electricity and chilled water, respectively, at the current utility rates. The steam usage increased slightly and cost an extra $1,739. A comparison between the total energy

demand in Fiscal Year 2002-03 and the simulated Base and Proposed Models of the Dana Building is also made. Challenges in the modeling process are highlighted and directions for future research are discussed. A recommendation for future research includes the application of an uncertainty analysis to the building energy simulation for LEED^{TM} credits in the Energy & Atmosphere category.

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

First and foremost, I must thank my advisors Gregory Keoleian, Alan Daly and Thomas Gladwin without whose help this project would not have been completed.

In Gregory Keoleian I have seen a dedicated teacher who not only teaches but also practices what he teaches: “environmental sustainability”. His simplicity and dedication in the classroom has always inspired me. He helped me a great deal in formulating my project topic. We spent many hours questioning the direction of my research and the validity of my results.

In spite of his busy schedule and the time difference (3 hours between EST & PST), Alan Daly always found time to guide me through my project, listen to my concerns and help me get un-stuck. His patience and dedication to his work has taught me a lot. Thank you.

Thank you Tom for helping me read through my project and complete it in a timely manner.

I would also like to thank Bill Verge and Cynthia Fowler at the Utilities & Plant Engineering, University of Michigan for all their help with providing important utilities data without which this project would not have been complete.

For their unconditional love, I am eternally grateful to my family. Their constant encouragement and support is always a comfort for me.

Finally I thank my best friend and husband, Sridhar Machiroutu, for having always been there for me. Sridhar has been there for me during my moments of disappointments and successes. He has always been patient and supportive in all my decisions. His belief in me has been a constant source of inspiration. Thank you with all my heart.

1 INTRODUCTION

1.1 Environmental Impact of Buildings

Buildings place dominant demands on the U.S. use of natural and energy resources and are responsible for a very large share of U.S. environmental emissions. Buildings account for a $222 billion annual energy bill, while using 36% of the nation's energy resources directly, 40% when one takes into account energy used in construction and demolition, and possibly over 50% when all of the energy-related factors are included that are necessary to serve buildings and their occupants[1]. Buildings consume 66% of the nation's use of electricity, thereby tying up the output of 2/3 of all of the nation's electric power plants. This direct and indirect use of energy accounts for 35% of US carbon emissions, 47% of the nation's emission of SO_2, and 22% of Nitrogen Oxides[1]. A major proportion of the flow of raw materials into the US economy goes into the construction of buildings, while the amount of those resources converted annually to construction and demolition waste rivals the US burden of municipal garbage.[1]

Buildings are an exceedingly complex industrial product with a lifetime of decades. Emerging health issues related to the environmental impacts from buildings, such as the so-called “sick building” syndrome, have intensified awareness of the role buildings play on our environmental well-being. While certain efforts have been on-going to control and manage individual aspects of the environmental qualities of buildings (i.e. energy codes, automation and control schemes, thermal comfort), comprehensive approaches have been lacking,[2, 3] particularly in the design stages of a building’s life span. On the other hand it is in the design stage when the greatest opportunities are available to affect changes whose benefits can last for decades. In the last decade new methods have emerged that regard buildings as a network of interrelated environmental impacts and address to juggle these impacts to create a more integrated and environmentally benign building[4]

1.2 Environmental Assessment of Buildings: LEED™ Green Building Rating System

There has been significant research focused on specific aspects of buildings such as building materials, equipment performance and simulation of building physics. Much research has also explored building-related environmental performance in areas such as energy consumption, daylighting, recycled materials and air quality. However as owners, designers, regulators and occupants increasingly desire that the entire building provide improved environmental performances, better integration of these individual objectives is required.

Generally, integrated approaches to understanding environmental impacts falls under the description of environmental assessment. Assessment has the dual goals of documenting environmental impacts and communicating those impacts to an intended audience. Any given party may conduct an environmental assessment for internal purposes or it may be part of a larger effort to communicate environmental information to consumers, regulators or investors. Currently, there are several methods that attempt to assess environmental impacts related to buildings. Each system has its own set of assumptions and limitations, each is designed to address certain aspects of environmental impacts and further, each system is designed for utilization by different participants in the building process, a condition that can "profoundly influence the outcome".[5]

LEED™ is a relatively new program that has emerged in the U.S. and is the only national "Green Building" rating system. The Leadership in Energy and Environmental Design (LEED™) rating system is not the first green building program in the U.S. but it is the only program with national scope and the only program that has been adopted by many private organizations as well as local and federal government bodies.

1.2.1 History of LEED

The U.S. Green Building Council (USGBC) is a nonprofit organization that was formed in 1993. The USGBC is made up of building industry stakeholders such as architects, building product manufacturers, owners, contractors and environmental groups who are interested in the promotion of green buildings in the U.S. The USGBC is a committee-based, voluntary, nongovernmental organization. Early council members advocated the development of a system to define green buildings. After researching existing programs (especially the British BREEAM (Building Research Establishment's Environmental Assessment Method) and Canadian BEPAC(Building Environmental Performance Assessment Criteria)) and metrics the council decided to develop a custom system for U.S. buildings. In 1998 the LEED 1.0 pilot program was released. By March 2000, 12 buildings had been certified under the pilot program. During the pilot period extensive revisions were underway and by March 2000 LEED 2.0 was released. LEED^{TM} is developed by a steering committee of the USGBC, which coordinates input from each of the different LEED^{TM} programs (LEED for New Construction, LEED^{TM} for Existing Buildings, LEED^{TM} Commercial Interiors, LEED^{TM} Residential, LEED^{TM} Core and Shell, and LEED Multiple Buildings). This report only concerns LEED^{TM} for New Construction and Major Renovations (LEED-NC), contained in the LEED 2.0 reference guide[6]. Five Technical Advisory groups (TAGS), one for each impact area of LEED^{TM}, define program features. The TAGs, made up of "expert" volunteers from the building industry, also resolve program interpretation issues and work on revisions to the program. The LEED^{TM} steering committee also "directs technical issues that require expert research and consideration"[7] to a technical Scientific Advisory Committee.

LEED^{TM} has experienced exponential growth in the U.S. since the release of LEED 1.0 in 1998. Council membership has grown to nearly 3000 leading organizations including: local and national architectural and engineering firms; product manufacturers such as Johnson Controls, Ford Motor and Herman Miller; environmental organizations such as the Natural Resources Defense Council, Global Green and the Rocky Mountain Institute; building industry organizations such as the Construction Specification Institute and the American Institute of Architects; building developers such as Turner Construction and Bovis Lend Lease, retailers and building owners such as Starbucks; financial industry firms such as Bank of America. LEED has also been adopted by the Federal (GSA, U.S. Air Force, U.S. Army of Corps of Engineers, Dept. of State, Dept. of Energy, EPA and the U.S. Navy), State (CA, MA, MT, NJ, NY, OR and PA) and local (Austin TX, Arlington VA, Boulder CO, Cook County IL, Los Angeles CA, Portland OR, San Diego CA, San Jose CA, San Mateo CA, and Seattle WA) government bodies.

There is international interest in the LEED™ program from Australia, France, Hong Kong, Japan, Canada, China, India and Spain. The latter four countries have registered projects for LEED™ certification.

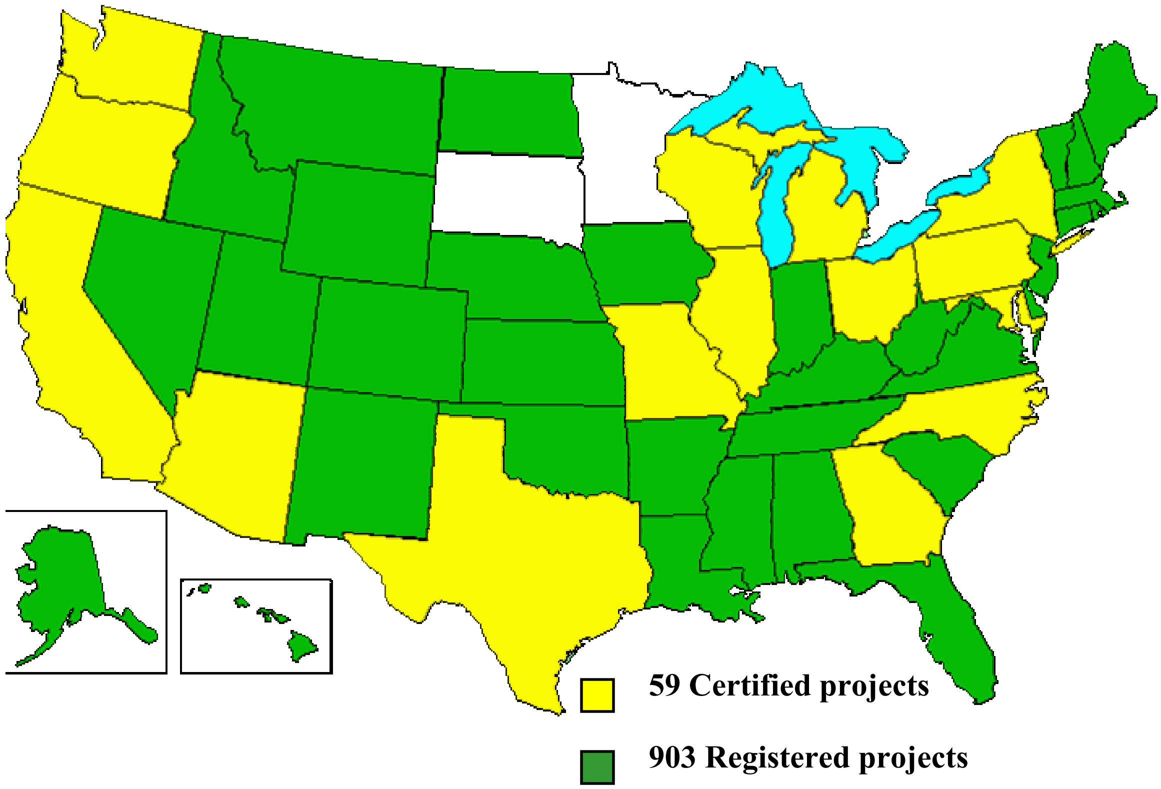


Figure 1: LEED – NC Market transformation (Source: USGBC)

Since the release of LEED 2.0 in March 2000, over 900 project teams have registered their buildings, representing 122 million ft^2 (not including parking) in 48 states in the U.S. and seven countries all over the world, thus expressing their intent to apply for official LEED™ certification by the U.S. Green Building Council. See Figure 1 for the states that have registered projects and those that have certified projects in the U.S as of July 2003. Figure 2 shows the area in gross square feet of the building projects in the different states in the U.S. as of July 2003. Figures 3 and 4 show the categories of projects by building type and owner type that have registered for LEED™ certification.

–

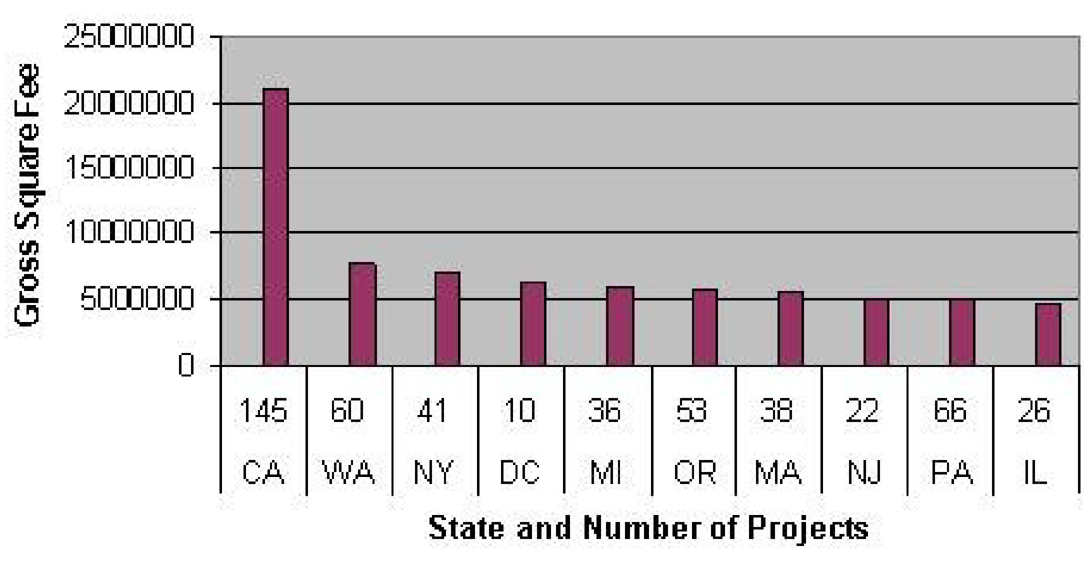
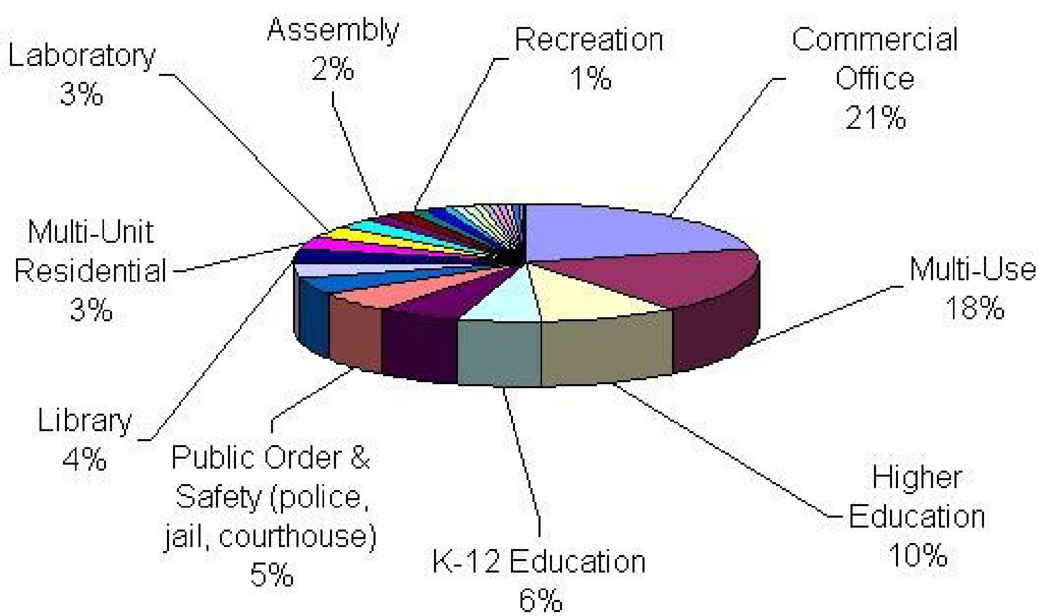


Figure 2: Registered projects by State (as of July 2003) – Top 10 (Source: USGBC)



-

Figure 3: Registered Projects by Building Type (as of July 2003) (Source: USGBC)

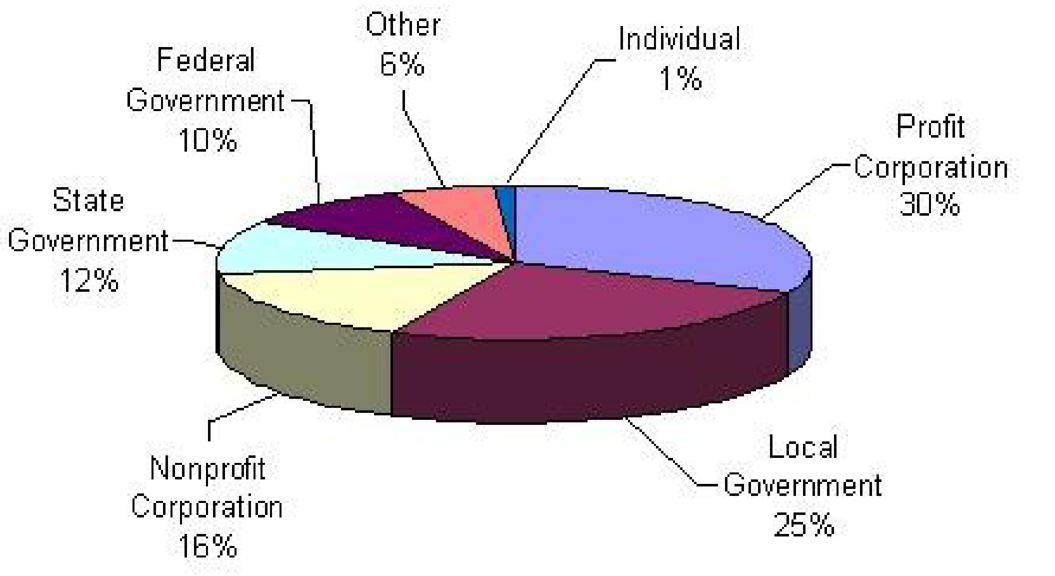


Figure 4: Registered Projects by Owner Type (as of July 2003) (Source: USGBC)

1.2.2 LEED™ Program Organization

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System™ is a voluntary, consensus-based standard for developing high-performance, sustainable buildings. Its goal is to "evaluate environmental performance from a whole building perspective over a building's life cycle, providing a definitive standard for what constitutes a 'green building'". LEED™ standards are currently available for:

1. New construction and major renovation projects (LEED-NC)
2. Existing building operations (LEED-EB, Pilot version)
3. Commercial interiors projects (LEED-CI, Pilot version)

According to USGBC, LEED™ was created for the following reasons:

1. Facilitate positive results for the environment, occupant health and financial return
2. Define "green" by proving a standard for measurement
3. Prevent "green-washing: (false or exaggerated claims)
4. Promote whole-building, integrated design processes

The LEED™ program is a credit-based system. There are four possible levels of certification:

- LEED™ certified: 26 -32 points
- Silver level: 33 - 38 points
- Gold level: 39 -51 points
- Platinum level: 52+ points (69 possible)

The credit points are divided among 5 environmental impact areas as shown in Figure 5. In addition there are 5 credit points for *Innovation and Design Process* activities.

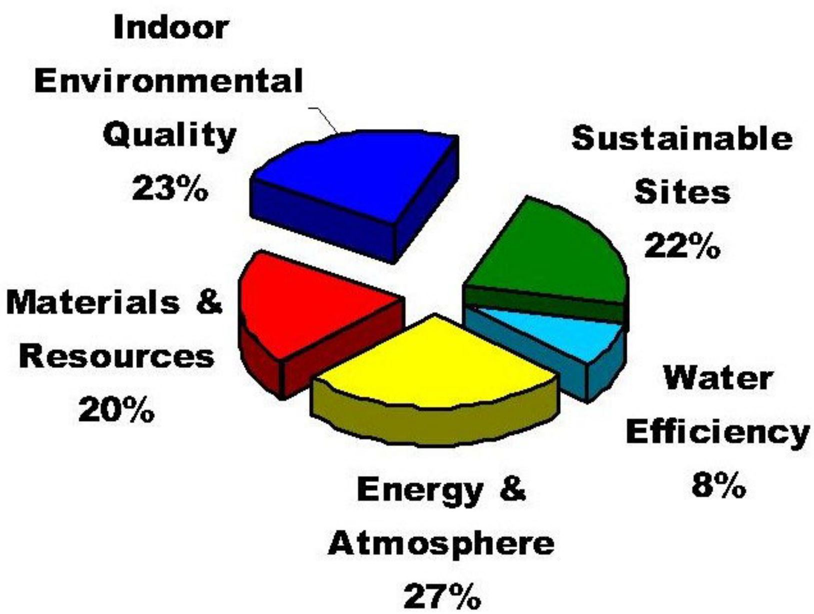


Figure 5: Five LEED™ Credit categories (Source: USGBC)

There are prerequisites in 4 of these areas that every building must meet and several credit options in each area. Many credits have several tiers for increasing performance achievements. In order to earn a LEED™ certification a minimum of 26 points must be achieved (in addition to all the prerequisites). (See Appendix A for a complete credit list).

Every credit consists of a description of intent, requirements and documentation submittals. In many cases there is a referenced standard and credit calculation procedures.

Credit requirements are accompanied by descriptive information about economic, environmental and community issues related to the credit. In many cases, examples and additional resources are also listed.

The LEED™ process consists of registering a building and then fulfilling the credit requirements and submitting the required documentation. Additional costs for the LEED™ certification process can run into tens of thousands of dollars. (See Appendix B for a Fee Summary).

Some benefits outlined by USGBC for LEED™ Certification are:

- Third part validation of achievement
- Qualify for growing array of State and Local government incentives
- Contribute to growing knowledge base
- LEED™ certification plaque to mount on building
- Official certificate
- Receive marketing exposure through USGBC website, case studies and media announcements

1.3 Motivation for Project

It is not unusual for builders to incorporate elements of "green" design in their new projects. But it is much more challenging to renovate an existing structure and incorporate "green" design elements. The former SNRE Dean Daniel Mazmanian had rightly pointed out that "Renovating a century-old building produces additional challenges when the builders hope to make it environmentally sound."

The University of Michigan's School of Natural Resources and Environment is located in the S.T. Dana Building which is recently completed a $25 million renovation. Its hundred-year-old infrastructure was upgraded and classroom and office space was added. At the same time, all facets of the renovation were performed with an eye toward environmental responsibility. Everything from scrap disposal to the finishing materials was driven by "green" building practices. Popularly called "The Greening of Dana", some of the goals of the project are, energy conservation and efficiency, use of renewable energy, increased daylight use, improved indoor air quality, water conservation, increased recycled content/recyclability of building materials and maximum reuse and recycling of components and materials from demolition.

This project is part of the process toward obtaining a Gold Rating of the S.T. Dana Building – Phase II Renovations project from the United States Green Building Council (USGBC) under their Leadership in Energy and Environmental Design (LEED^{TM}) Green Building Rating System for New Construction and Major Renovations (LEED-NC). At the time this report was written, Carl Elfante, an architect at Quinn Evans Architects and member of the University of Michigan LEED^{TM} Committee estimated that a Gold Rating will be attained based on credits awarded within all categories (Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality and Innovation & Design Process). The estimated score up until then was 41 points (39 required for Gold Rating), 6 potential points and 21 not available (see Appendix C for a draft of the complete list of Credits for the Dana Building thus far). Under the Energy and Atmosphere category, apart from 3 prerequisites, up to 10 points can be earned for optimizing energy performance, up to 3 points for renewable energy and 1 point for green power. A total of 17 possible points can be earned under the Energy and Atmosphere category. The Phase II renovations include energy conservation strategies such as insulation of the building envelope and the addition of the radiant cooling system. These improvements will enhance energy performance enough to contribute 4 credit points (2 each for Credit 1.1 and Credit 1.2) under the Energy & Atmosphere category.

The LEED™ Rating System has certain requirements and documentation submittals that are necessary to achieve one of four possible levels of certification (LEED™ certified, Silver, Gold and Platinum, the later being the highest rating). In order to evaluate optimized energy performance of the Dana Building, a computer simulation model is used to assess the energy performance and identify the most cost effective energy measures. The energy performance has to be quantified and compared to a baseline building that complies with ASHRAE/IESNA Standard 90.1-1999 (without amendments) or the local code, whichever is more stringent.

As part of this project energy simulations of the of the Dana Building have been performed and documented to assess the energy performance of the renovated Dana Building with a baseline building that complies with ASHRAE Standard 90.1-1999, for submittal to the University of Michigan LEED™ committee. This analysis will form a part of the documentation that will be submitted to USGBC for LEED™ certification of the S.T. Dana Building.

1.4 Background on Building Space Conditioning

For thousands of years, people have used a variety of architectural techniques (thermal mass, shading, vents, courtyards etc.) to adapt dwelling design and cultural practices to local climate conditions. After the industrial revolution, many of these techniques such as courtyards and airshafts were adapted to the new requirements of large buildings. Since Carrier invented the refrigerant chiller in 1902 there has been a revolution in conditioning buildings. Mechanical cooling of buildings became widespread in the United States only after World War II, when the electrification of the American South progressed and air-conditioning moved from movie theaters to factories, homes, offices, department stores and even automobiles. By the 1950s, the reliability of air-conditioning, the adoption of fluorescent lights and of solar control glazing, and the falling price of electricity, allowed architects to abandon proven techniques of climate-responsive design, and instead focus on the aesthetic side of design. Today, even out-door facilities (football stadiums, zoos, amusement parks, etc.) are air-conditioned. Air-conditioning is ubiquitous; its presence has become the expected norm.

One of the consequences of today's intensive use of air-conditioning is that building professionals have lost much of their ability to design climate-responsive buildings. The compartmentalization of the building profession[8], and the divergent interests of the different parties involved in the building process, make modern buildings costlier to build, and considerably costlier to cool and ventilate than need be. In addition, worker surveys reveal that commercial building occupants are increasingly dissatisfied with the thermal conditions of their workplace[9] and that occupant exposure to air-conditioned indoor environments sometimes leads to adverse health conditions[10].

Since the energy crisis of the 70s much attention has focused on incorporating energy efficient technologies into building design that directly address energy and environmental problems. While alternative cooling technologies are intensively used in new construction and retrofit projects in Western Europe, the relatively low energy prices in the U.S., together with the decentralization and fragmentation of the building industry, have been a barrier to the large-scale implementation of alternative cooling technologies in the United States.

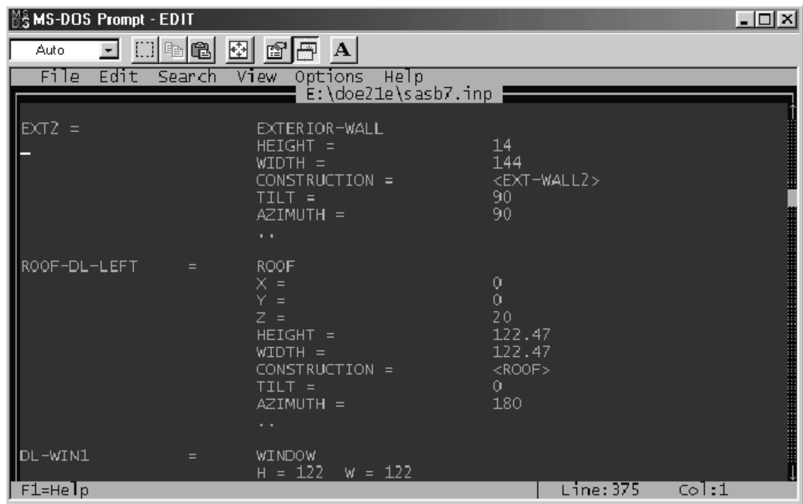
1.5 A Brief Note on Building Simulation

From operating costs, to energy efficiency, to broader issues of sustainability, the quality of building design decisions can only be as good as the information entering the design process, i.e., the performance levels our building design projects ultimately realize is a function of how well informed our design decisions are. Building energy performance simulation is a powerful tool that architects, engineers, and developers use to analyze how the form, size, orientation, and type of building systems affect overall building energy consumption. This information is vital for making informed design decisions about building systems that impact energy use, including envelope, glazing, lighting, and HVAC. It is often the case that a few building simulation runs in the early phases of a project can lead to design solutions that, though they appear simple, significantly improve building energy performance.[11]

It is hard to estimate the annual energy costs associated with operating a building, while it is still under design. The answer depends on numerous factors, including the construction details and orientation of walls and windows, occupancy patterns, local climate, operating schedules, the efficiency of lighting and HVAC systems, and the characteristics of other equipment loads within the building. Accounting for these variables, as well as their interactions, is a daunting task, especially because some change by the hour. Given this complexity, rigorous calculations of annual building energy costs were rarely performed before personal computers became commonplace.

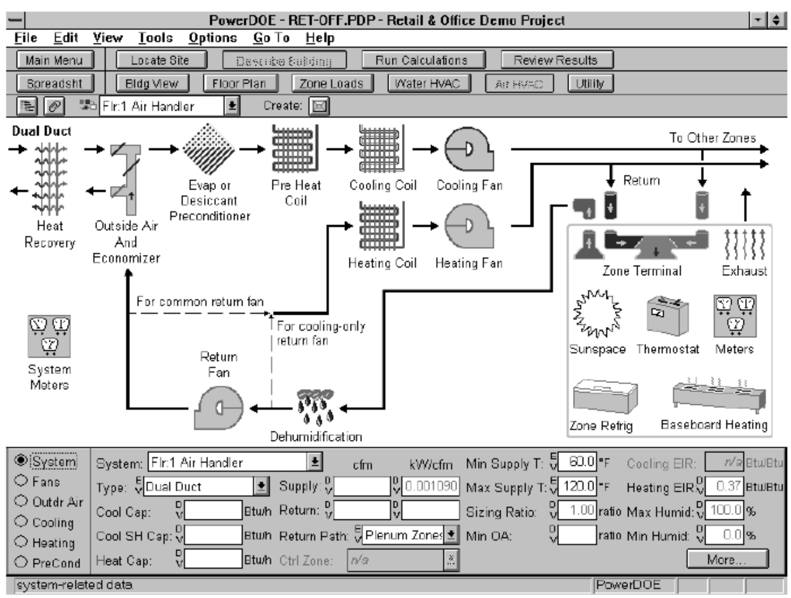
Software packages for building energy performance simulation solve the numerous and complex equations that describe how buildings use energy. The most sophisticated of these programs are capable of calculating building energy consumption hour by hour for an entire year. The best-known hourly simulation software package is DOE-2 (developed by the Simulation Research group at Lawrence Berkeley National Laboratory). Using DOE-2 is difficult and there are few practitioners who can apply it effectively. Figure 6 shows the DOS based user interface of DOE 2.

Several efforts have been made to make building simulation more accessible to designers and developers. For example, several versions of DOE-2 are now available with graphical user interfaces, which greatly facilitate data input (See Figure 7). Simplified hourly simulation tools, such as eQUEST^{TM} make simulation much easier to use them than the current version of DOE-2, but place many more limitations on the user[11].



Source: CTG Energetics

Figure 6: DOS Based Text Editor User Interface of the Simulation program DOE 2.1 E



Source: EPRI

Figure 7: Advanced Windows Based User Interface of Simulation program PowerDOE

1.6 Project Report Outline

Chapter 2 describes the Project Objectives. It also discusses the assumptions and boundaries of research. Methodology used in this study is described in detail in the second half of this chapter.

Chapter 3 describes the S.T. Dana building, its history and the “Greening of the Dana” renovation project in detail. It also presents the historical energy data used by the Dana Building in order to place the results of the project’s energy analysis into context.

Chapter 4 is a summary of the present state of knowledge about radiant cooling systems. It contains a short history of the radiant cooling systems, performance of radiant cooling systems and a comparison of the advantages and disadvantages of radiant cooling systems compared with traditional air-conditioning systems. It also has a description of the current knowledge in simulating a radiant system using building energy software to evaluate its performance. A description of the new radiant cooling system in the S.T. Dana building is also included.

Chapter 5 describes the building energy model that was built using the energy software, eQUEST^{TM}. All inputs including building envelope, lighting, equipment, occupancy and HVAC systems used in the model are described in detail in this chapter.

Chapter 6 has the utility rates that were used in the simulation to calculate percentage of cost savings for LEED^{TM} credits. This data is from the Utilities & Plant Engineering, University of Michigan

Chapter 7 describes the results of the energy analysis from the simulation. It has information that shows a comparison of the electricity, steam and chilled use and cost of the renovated Dana Building with the Base case model.

Chapter 8 gives a summary of the energy efficiency measures used in the S.T. Dana building. Drawing from the results of the project and discussion in this report, this chapter ends with conclusions of the energy analysis and also identifies directions for future research.

2 RESEARCH METHODS

2.1 Project Objective

The project objective is to evaluate energy use and the energy efficiency performance of the Phase II renovations of the S.T. Dana Building Renovation project. The Phase II renovations of the S.T. Dana Building have been modeled using the eQUEST^{TM} energy analysis software. eQUEST^{TM} uses the DOE 2.1 building energy simulation engine. The purpose of this report is to document the Dana building energy modeling efforts and present the analysis and findings related to the LEED^{TM} Energy and Atmosphere Prerequisite and Credit Documentation. It is used to demonstrate that the building meets the LEED^{TM} energy efficiency prerequisite (complies with ASHRAE 90.1-1999) and further qualifies for LEED^{TM} energy efficiency points.

This project also highlights the limitations of the existing building energy simulation programs to simulate various systems such as radiant cooling system used in the S.T. Dana Building. There are some assumptions made based on secondary research and communicating with experts in the field of simulation to incorporate the radiant cooling system in the analysis.

2.2 Methods

The LEED^{TM} requirements earning credits in the Energy and Atmosphere category were carefully studied (see Table A in the Appendix). The second prerequisite, “Minimum Energy Performance” in the Energy and Atmosphere category is mandatory and its intent is to establish the minimum level of energy efficiency for the base building and systems. This prerequisite requires the designed building to comply with ASHRAE/IESNA Standard 90.1-1999 (without amendments) or the local energy code, whichever is more stringent. There is no credit for the prerequisite; it is required for eligibility to apply for LEED^{TM} accreditation. A computer simulation model was built using eQUEST^{TM} building energy software to demonstrate that the renovated Dana Building complied with ASHRAE/IESNA Standard 90.1-1999.

Optimize Energy Performance credits could earn the project up to 10 potential points. The intent of this credit is to achieve increasing levels of energy performance above the prerequisite standards to reduce environmental impacts associated with excessive energy use. The credit requires a reduction of design energy cost (renovated project) compared to the energy cost budget (base case) for energy systems regulated by ASHRAE/IESNA Standard 90.1-1999 (without amendments) as demonstrated by a whole building simulation using the Energy Cost Budget method described in Section 11 of the Standard. Table 1 shows potential LEED™ points that can be earned with increasing levels of energy performance over the prerequisite standards.

Table 1: LEED Points earned as a percentage of Energy savings

Existing Buildings **ASHRAE 90.1 Scale (Energy Savings)**	**LEED Points**
5%	1
10%	2
15%	3
20%	4
25%	5
30%	6
35%	7
40%	8
45%	9
50%	10

The simulation process begins by developing a "virtual model" of the building based on the architectural building plans and specifications. A base line building model (called the Base Case Model) that has minimal compliance with ASHRAE 90.1-1999 is then developed. The Proposed Case Model is made by making changes to the Base Case Model that correspond to efficiency measures that are implemented in the building. Annual utility consumption and cost savings are used to determine percentage of cost savings of the Proposed Model over the Base Model and that in turn is used to estimate the prescribed LEED™ credit points. The building geometry for the Base Case and the Proposed Case is the same. The radiant cooling panels are modeled in the Proposed Case as a fan-coil unit with infinite fan efficiency to simulate zone cooling without any fan energy use. Since radiation only affects surfaces directly without affecting the air in between, the room temperature has been elevated from 75ºF to 78ºF. Human comfort in these zones is equivalent because the occupant is cooled directly by the panels.

Unit of measure for the performance is annual energy cost expressed in dollars. Annual energy cost is determined using rates for purchased energy such as electricity, steam and chilled water received from the Utilities & Plant Engineering, University of Michigan. The Utilities Department charges only for steam and electricity, they do not have an explicit utility rate for the chilled water. Even if the Utilities Department gave us the amount of electricity and steam that were charged for chilled water, assumptions would have had to be made to determine the rate for chilled water. Fortunately, Bill Verge, Director of Utilities & Plant Engineering recently completed a cost study for the chilled water plant and provided a chilled water rate that could be directly used to calculate savings from reduced chilled water demand in the Proposed Case.

2.2.1 Choosing the right Building Simulation Tool

When one decides to perform a building simulation, the first and perhaps most important decision is to decide the appropriate simulation tool. There are several software choices such as DOE-21. Code, Power DOE, Visual DOE, Energy Plus, Energy 10, eQUEST^{TM}, Energy Pro, EcoTect, RIUSKA, TRNSYS, Perform 2002, Trane Trace 600 and Carrier Hourly Analysis program (HAP). (See Appendix D for a comparative list of some building simulation tools). The decision should be based on one's level of familiarity with building simulation, the type of questions one wishes to answer with the model, and the required level of detail. One must try to match model complexity to building complexity. For a quick design solution where the designer is not familiar with complex building inputs, he or she must stick to simpler, user-friendly tools such as eQUEST^{TM}. This will allow one to focus on the program inputs and not on program syntax. To evaluate specific technologies, such as daylighting controls, a program capable of handling such technology must be selected. Finally if the building simulation results are to be used to document compliance with local energy codes, one must make sure that the program selected is approved by the project's building department that has jurisdiction over the project[11].

2.2.2 Simulating a Radiant Cooling System

Designers have struggled for sometime to make a fair and accurate performance comparison between conventional and radiant based space conditioning systems. Research has been conducted by various organizations and institutions, such as ASHRAE, Lawrence Berkeley National Labs, Kansas State University and Building Systems Laboratory at University of Illinois to develop criteria for analyzing radiant cooling systems.

LBNL worked on a research tool based upon the SPARK (Simulation problem Analysis and Research Kernel) module which provides a methodology for describing and solving the dynamic, non-linear equations that correspond to complex physical systems[22]. Kansas State University researchers developed a three dimensional mathematical model to compute the radiant heat exchange between surfaces separated by a transparent and/or opaque medium. This was further integrated into a thermal comfort design methodology called BCAP (Building Comfort Analysis Program)[12]. The Building Systems Laboratory at University of Illinois authored the Building Loads Analysis and System Thermodynamics (BLAST) model that is capable of modeling transient heat transfer analysis. A research version called Integrated BLAST or simply IBLAST adds the feature of including radiant heavy exchange analysis[13].

These studies have been motivated by the desire to achieve the ability to safely and accurately predict the performance of radiant systems. They are also indicative of the tradeoffs involved between accurate prediction and computational speed. Many of the tools discussed above including BCAP are essentially steady state solutions adapted to include the radiant component, and are not designed to analyze mass behavior in detail. Tools such as SPARK and BLAST have attempted to varying degrees of success a holistic analysis of radiant systems and mass properties. SPARK has remained a research tool and is available in beta formats; further details about this particular tool were not available. BLAST is probably the best suited software for mass analysis as it is essentially a transient multi-dimensional analysis tool that takes into account mass properties such as heat capacitance, thermal storage etc. However, the radiant capacity is not fully developed, and a full analysis of radiant system efficiency is not possible. DOE-2 based tools are essentially steady state solutions and they rely on pre-calculated averages and factors to simulate mass performance.

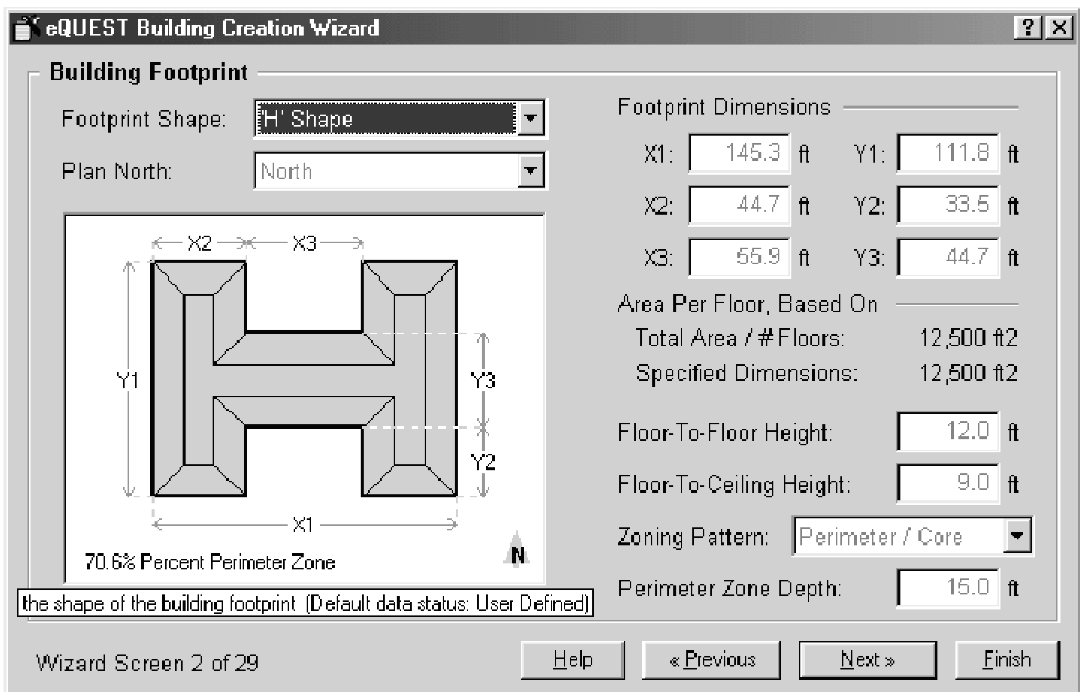
EnergyPlus is a new simulation software (it combines the best features of the DOE-2 program and IBLAST program) that was released by the U.S. Department of Energy in April 2001. In addition to the ability to model configurable forced air systems, the initial release of the new program also included models for low temperature radiant heating and cooling systems (electric & hydronic) and high temperature radiant heating systems.

At the time of the beginning of this project, EnergyPlus was new and untested and therefore it was not used in spite of its ability to simulate a radiant cooling system. Based upon the existing research and software for simulating a radiant cooling system, the eQUEST™ program was used and certain assumptions made to simulate the radiant system.

2.2.3 eQUEST^{TM}: Building Simulation Software

The eQUEST^{TM} building simulation software was used for this project. Following is a short description of the software's capabilities and drawbacks.

eQUEST^{TM} is a sophisticated yet user friendly building energy use analysis tool that provides professional level results with an affordable level of effort. This tool is available free on the internet. eQUEST^{TM} has a Windows based user interface for the DOE-2.2 calculation engine that allows the user to select from a number of predefined building forms, enter some project specific data, and then run a full-blown DOE-2 simulation (See Figure 8).



Source: Energy Design Resources

Figure 8: Windows based User Interface of Simulation program eQUEST^{TM}

eQUEST^{TM} calculates hour-by hour building energy consumption over an entire year (8760 hours) using hourly weather data for the location under consideration. Input to the program consists of a detailed description of the building being analyzed, including hourly scheduling of occupants, lighting, equipment, and thermostat settings. eQUEST^{TM}

provides very accurate simulation of building features such as shading, fenestration, interior building mass, envelope building mass, and the dynamic response of differing heating and air conditioning system types and controls. eQUEST^{TM} also contains a dynamic daylighting model to assess the effect of natural lighting on thermal and lighting demand. Most projects can be input in well under an hour, and the program produces a wide variety of graphical outputs that will help you compare design alternatives. The author has used the detailed interface in eQUEST^{TM}, where the input process is more elaborate in order for the model to better characterize the real building as closely as possible.

eQUEST^{TM} is supported as part of the Energy Design Resources program which is funded by California utility customers and administered by Pacific Gas and Electric Company, San Diego Gas & Electric, and Southern California Edison, under the auspices of the California Public Utilities Commission.

2.2.4 Typical Simulation Inputs

There are seven steps within the four overall areas of the eQUEST™ simulation program, which has a DOE-2 derived engine. The seven steps in sequence are Loads: *Instantaneous Gain and Space Load*, Systems: *Heat Extraction and Coil Load*, Plant: *Primary Energy/Demand* and Economics: *Utility rate and Utility Costs*. Figure 9 below shows typical static and dynamic inputs within the four areas of the program.

DYNAMIC	INPUTS	STATIC
PEOPLE LIGHTS EQUIPMENT INFILTRATION	**LOADS**	CONSTRUCTION ZONING LOCATION
H/C SETUPS FANS VENTILATION	**SYSTEMS**	PEOPLE LIGHTS EQUIPMENT INFILTRATION
AVAILABILITY	**PLANT**	EQUIPMENT TYPE EFFICIENCY
	ECONOMICS	UTILITY RATES

Figure 9: System Simulation Inputs

2.2.5 Boundaries of Simulation

The Central Plant is not included in the simulation. The steam and electric meters' readings from the Univesity of Michigan Utilities are used for energy demand and utility rates. Figure 10 shows graphically the boundaries of simulation.

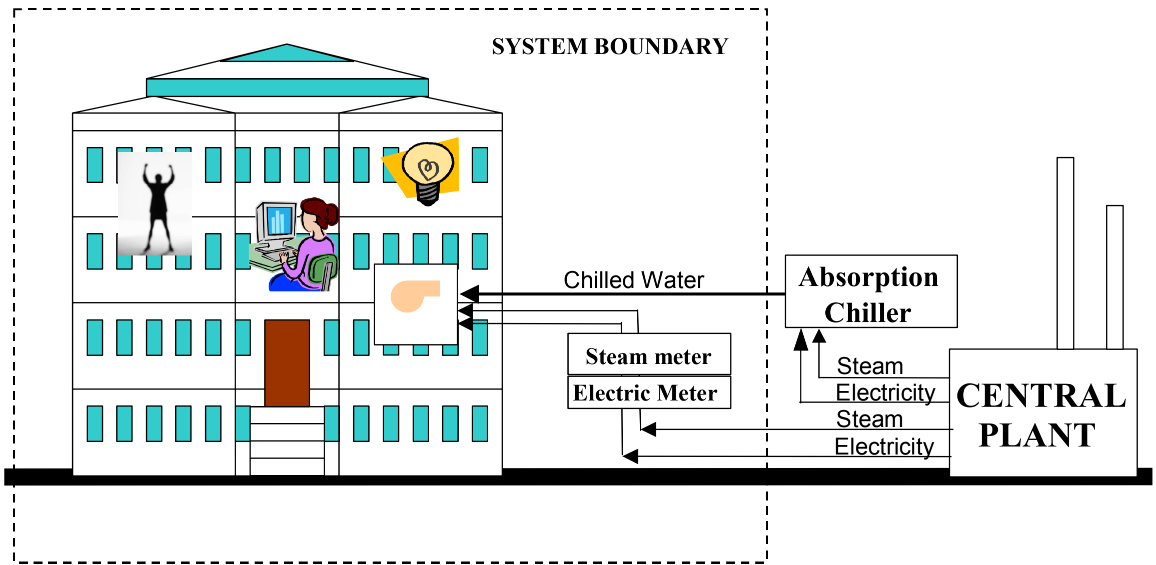


Figure 10: Boundaries of the Simulation

2.3 Data Sources

Data was obtained for the LEED™ rating analysis through interviews with the officials at Utility & Plant Engineering of the University of Michigan, constructions documents from the architects, consulting engineers and SNRE staff in charge of the project.

Wall, ceiling and floor insulation levels are as indicated in the construction drawings. The mechanical systems including the radiant cooling panel details are as indicated in the construction drawings as well.

The Utilities & Plant Engineering, University of Michigan provided the cost of utilities including, steam and electricity as well as historical energy consumption of the Dana Building.

3 BUILDING DESCRIPTION

3.1 S.T. Dana Building

The School of Natural Resources and Environment is located in the Samuel T. Dana Building on the northeast corner of the University of Michigan 'Diag' (main plaza) on Central Campus. Built in 1903 as the West Medical Building which housed the Medical School, this building was first occupied by SNRE, the School of Natural Resources and Environment in 1961 and was renamed to honor Samuel T. Dana who founded the first School of Forestry and Conservation at University of Michigan in 1927.

It has been through several renovations and has had different mechanical systems installed since its initial construction in 1903. As part of the centennial celebrations, S.T. Dana building's hundred year old infrastructure has undergone a $25 million renovation. The Renovation project popularly referred to as the 'Greening of Dana', is intended to result in a building where principles of environmental responsibility are not only taught, but upheld and demonstrated to the community. The project was divided into two phases, one of which is complete and the other is due to be completed in Winter 2003. Phase I (Spring1998 – Fall1999) comprised the filling in of the interior courtyard to create 11,000 square feet of program space, and the modification of the existing roof and attic to provide 2,250 square feet of mechanical support space resulting in the addition of a new fourth floor and a roof with a skylight. Phase II (Spring2001 – Winter2003) is a whole building renovation with innovative green building components.

The academic building contains approximately 105,000 assignable square feet of instructional space for students including classrooms and lecture spaces, office space for faculty and research laboratories that include an aquatics lab, a terrestrial ecosystems lab for soil analysis, an environmental spatial analysis lab, and three landscape architecture studios. The commons or the student lounge is a favorite place for students and is in the ground floor of the renovated building.

Figure 11: S.T. Dana Building in 1903

Figure 12: S.T. Dana Building – Pre construction

Figure 13: S.T. Dana Building – April 2001

The building is four storied and has a basement referred to as the ground floor in this report. The building is approximately square in shape and has entrances on the west and east side. The east side entrance is located on East University Street and the west entrance opens onto the University of Michigan Diag. Figures 11, 12 and 13 give a general idea of the building before and after renovations. The original building was a donut shape with a courtyard in the center. During the Phase I renovation, completed in the fall of 1999, a fourth floor was added, and more than 20,000 square feet of space was reclaimed by filling in the original courtyard with an atrium. The new spaces included a new student lounge on the ground floor, computer labs on the second floor and a reading room on the fourth floor. The attic was converted to a new fourth floor and the central space was covered with roughly 4,000 square feet of skylight, optimizing daylight penetration of the sun and providing natural light.

3.2 'Greening of Dana' Project Initiatives

Ann Arbor-based Quinn Evans Architects Inc. and Charlottesville, Va.-based William McDonough + Partners developed numerous "green'" renovations for the second phase. The SNRE community did not move to a new building when they needed to expand, instead they decided to renovate the existing building, thus minimizing their 'environmental foot print'. Landfill dumping was minimized whenever possible by looking for alternative destinations for the "waste" from the demolition. For example, Recycle Ann Arbor picked up more than 3,000 pounds worth of windows to be sold at its Re-Use Center according to Beth Murphy, who served as liaison between School and construction personnel with regard to waste management, recycling and salvage of materials. In many instances, original materials have been re-incorporated, including salvage brick and the original roof timbers (100 year old southern yellow pine timber), now transformed into tables, benches and trim. 3,000 courtyard paver bricks classified as waste by a contract were rescued from a dumpster by SNRE undergraduates, and will be used in the redesigned plaza. Throughout the building natural and recycled content materials are being used as much as possible. Rubber at the building entrances and on ground floor corridors and stairs is made from recycled tires, cabinets are made from sunflower hulls and wheat straw, suspended ceiling tiles are compressed aspen fibers, and

100 percent wool carpet is manufactured in Australia. Bathroom tiles composed of recycled glass and ceramic, certified sustainable harvested wood and low VOC paint are just some of the 'green' materials incorporated in the renovation.

The $15 million Phase II renovation involves major systems upgrades including new plumbing, heating, ventilation and hood exhaust systems, plus significant improvements to fire protection and handicapped accessibility systems according to former U-M Executive Vice president Robert Kasdin. About 39,000 net square feet of space is involved in this phase. Kasdin had also confirmed that the "Phase II project is part of the FY2000 Capital Outlay Request submitted to the State. The State, through its Building Authority will fund 75 percent of the cost of the project and The University of Michigan will fund the balance of the project cost (25 percent)".

There is also a proposal to install photovoltaic, or solar cell panels, on the roof to save fossil energy. The photovoltaic cell panels, combined with energy-saving bulbs and occupancy sensors that automatically turn lights off if a room is vacant will greatly reduce the building's energy consumption.

The forced-air system, to a large extent is being replaced with energy efficient radiant cooling systems. Other features include low-flow fixtures, faucet sensors, waterless urinals and two composting toilets.

3.3 Central Plant Description

The Dana Building is served by the University of Michigan Central Plant which provides steam and electricity to the building.

The Central Plant has a natural gas fired, cogeneration plant with fuel-oil backup. All steam turbines are 9psig back pressure machines, and the only condenser is the campus heating and cooling systems. There are two smoke stacks, the south is 150 feet and the north is 250 feet above the grade. Additional electric power if required is purchase from outside. Cooling provided to the Dana Building is generated by absorption chillers that have as their energy source the waste heat from the steam turbines described above.

3.4 Historical Energy Data for the S.T. Dana Building

Since its original construction in 1903, the Dana Building has undergone fragmented renovations over the last 100 years. The original system was a heavy-mass air distribution system with a big fan. There were code issues with this system, in part because the corridors where the return systems and the stacks left open potential smoke hazards. In the late 50’s and early 60’s, most of the earlier system was removed and replaced. There was still some steam radiation and some gravity ventilation shaft ways typical to that era. Some fireplaces and fans of the early years also remained.

A few of the steam radiators were replaced by heating water convectors. There were 4-5 steam heating and ventilating air handling units in the attic. In the 60’s there was no cooling in the building. There were also some exhaust fans. It was not much of a system by present day standards.

In the late 60’s through the 80’s, the Dana Building had a number of small packaged cooling units installed. These were in the form of scattered window air conditioners for cooling. After renovations in the late 80’s, chilled water came in the from the new Central East University plant below the Dennison Building. Fan-coil systems were used for some spot cooling, and one ground floor unit was installed to serve the new laboratories in the ground floor (below grade). Throughout this period there were a number of fume hoods, numerous exhaust fans and more window air-conditioners installed.

In 1992, a heating water and chilled water loop was installed on each floor with the intention that the heating and cooling fan-coils would be provided. Indeed several fan-coils were scattered through the building both above ceilings and by windows. Fan-coils continued to be installed in small quantities through the decade.

In the late 90’s, the atrium replaced the open courtyard and the first of what would be two air-handlers installed in the fourth floor mechanical room. The old attic units were removed. Large plenumized exhaust fans were provided for fume hood and other general exhaust. The small exhaust fans were removed.

The latest renovations were the following. Chilled ceilings replaced the fan-coils, utilized the existing loop in the past. A second air handler on fourth floor, a VAV (variable air volume) system provided air to the fourth floor. The ground floor unit was upgraded and there were numerous ventilation improvements[14]. The latest improved HVAC system is discussed in more detail in Chapter 4, section 4.7.4.

Figure 14 and 15 show the historical consumption of electrical and steam consumption as the building areas, heating and cooling demands, and occupancy changed over the years. The steam and electricity consumption includes the chilled water consumption as the Utilities & Plant Engineering, University of Michigan doesn't charge for chilled water separately. The electricity and steam consumption shown in the figures includes the electricity and steam required to produce the Chilled Water used by the Dana Building.

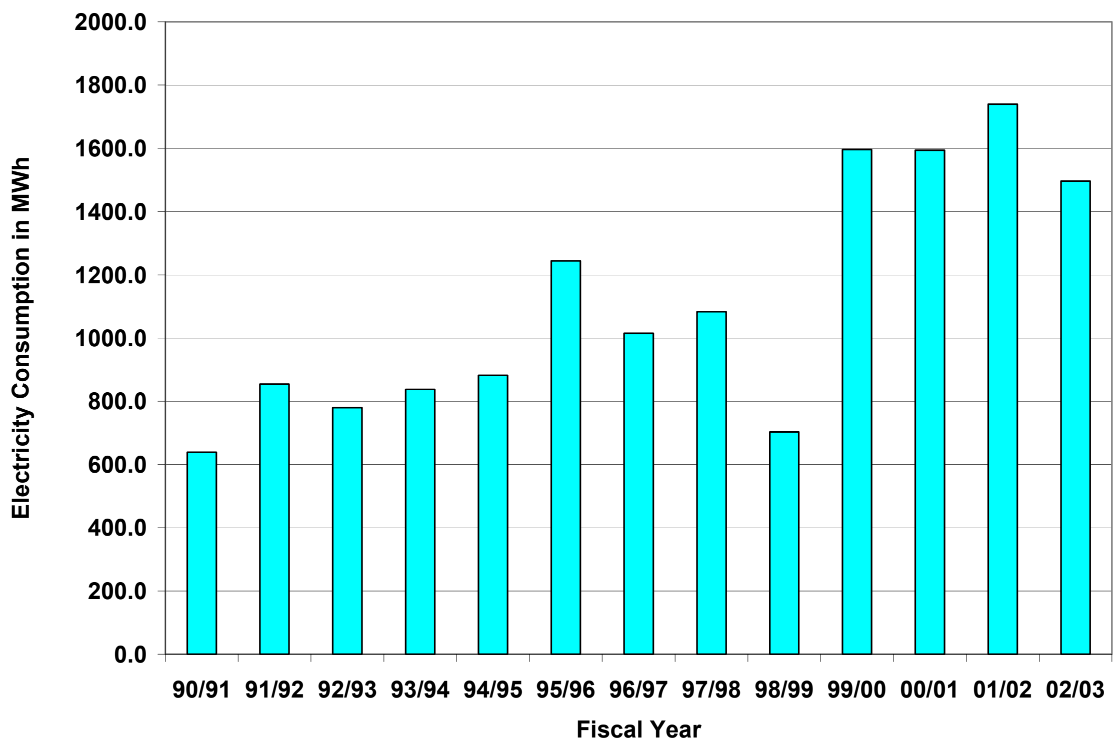


Figure 14: Dana Building: Historical Electricity Consumption (includes electricity for chilled water plant)

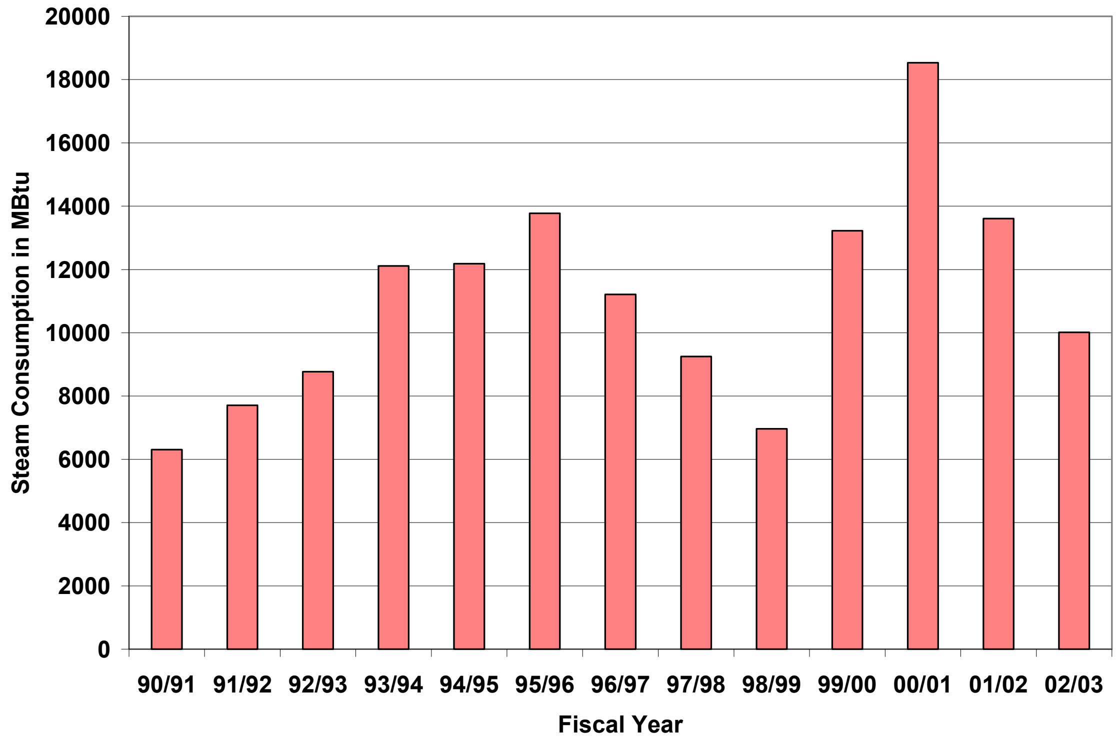


Figure 15: Dana Building: Historical Steam Consumption (includes steam for chilled water plant)

University of Michigan's Utilities & Plant Engineering only bills the Dana Building for Steam and Electricity. The cost of chilled water is included in the Steam and Electricity cost, Chilled Water is not separately billed.

For the Fiscal Year 2002-03, the Dana Building was charged for 4,355 Mbtu steam and 101, 963 KWh electricity for Chilled Water consumption[15]. These numbers were subtracted from the total billed steam and electricity consumption in the year 2002-03. This provided the steam, Chilled Water and electricity requirement for the building. The Chilled Water requirement thus calculated did not include the efficiency of the absorption chiller. Data provided by Bill Verge at the Utilities & Plant Engineering was used to calculate the efficiency of the East University Absorption Chiller that provided Chilled Water to the Dana Building. It was found that 1.8865 Btu of fuel (electricity and steam) was required to produce 1 Btu of Chilled Water (see Appendix E). Using this efficiency, the Chilled Water Demand for the Fiscal Year 2002-03 was calculated to be 2493 Mbtu. The energy consumption and its associated costs are shown in Figures 16 and 17. Note that in Figure 16, the electricity demand is converted to million British Thermal

Units to present on-site energy consumption from different utilities on the same graph. The chilled water term includes both steam and electricity that was charged for the chilled water. Figure 18 shows the percentage break-up of the contributing utilities and their costs.

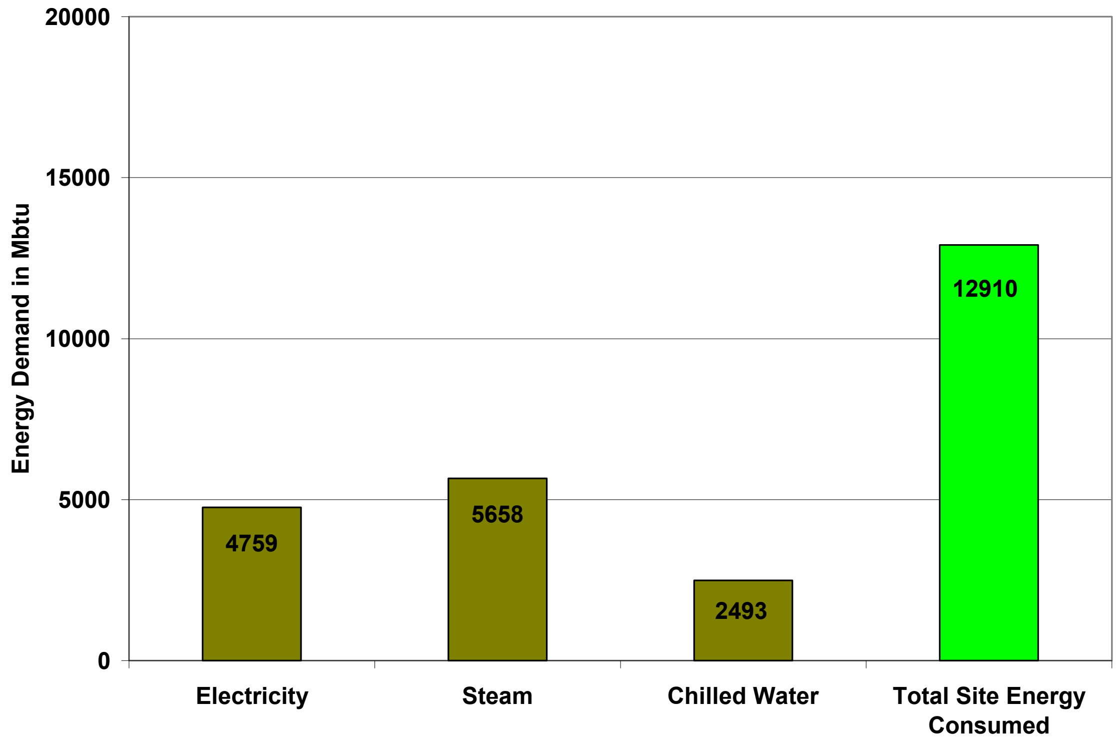


Figure 16: Dana Building: Total Site Energy Demand in Fiscal Year 2002-03

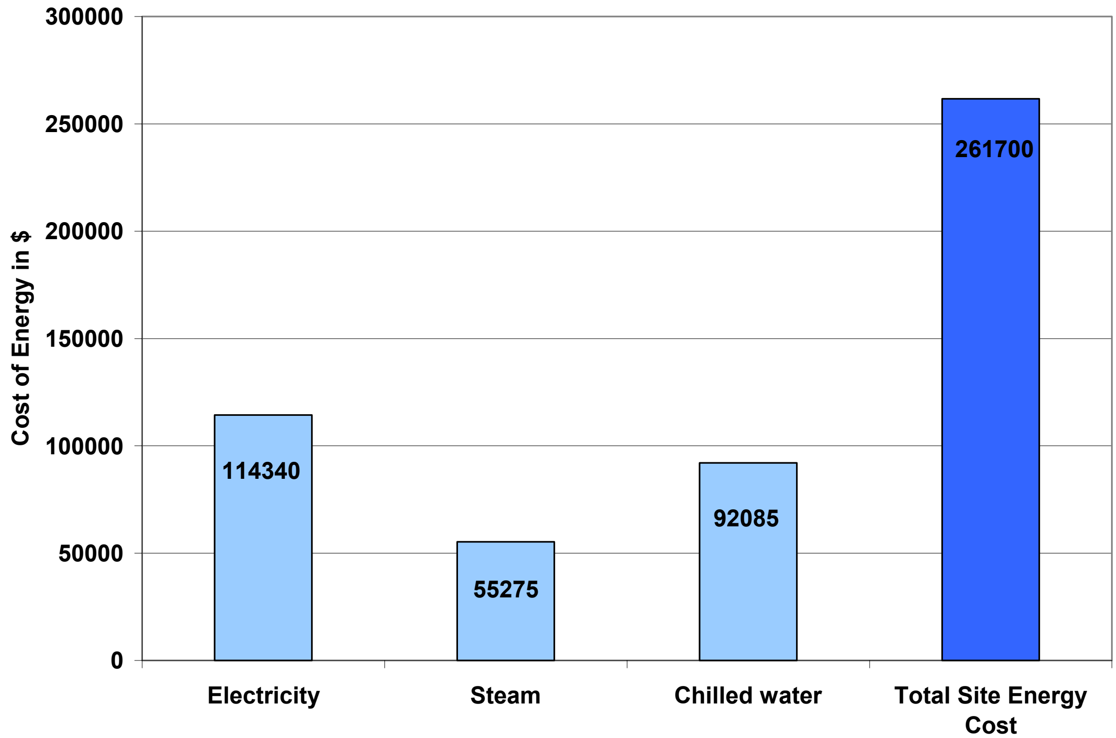


Figure 17: Dana Building: Total Energy Cost ($) for Fiscal Year 2002-03

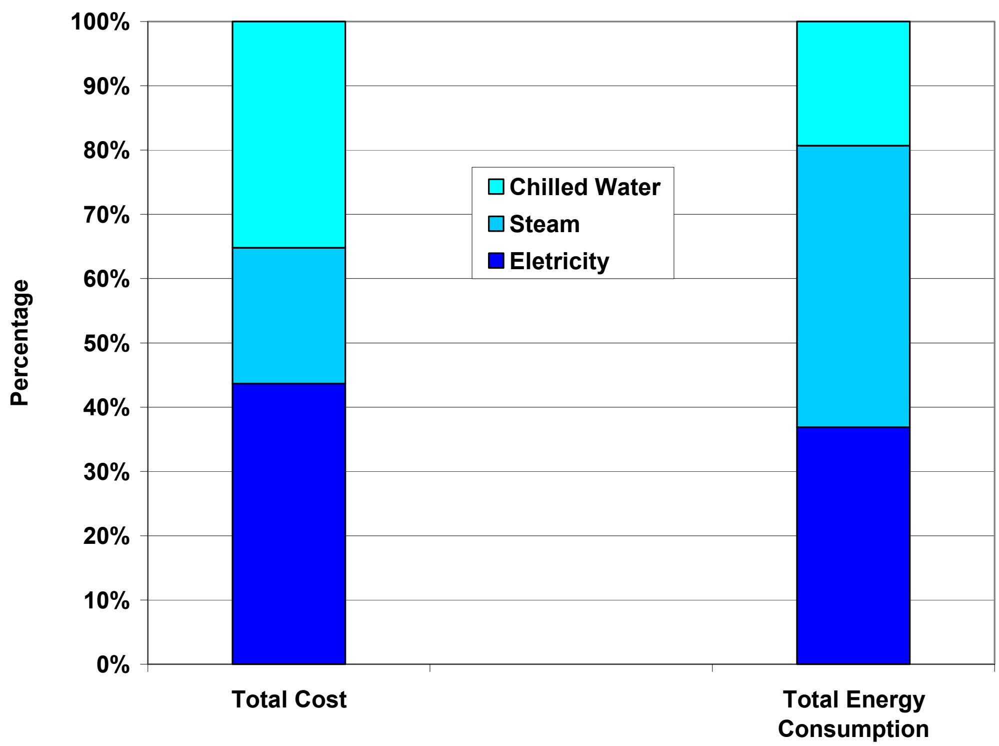


Figure 18: Dana Building: Site Energy Demand & Cost ($) for Fiscal Year 2002-03

4 RADIANT COOLING SYSTEMS

4.1 Introduction

Cooling nonresidential buildings in the U.S. contributes significantly to electrical power consumption and peak power demand[20]. One aspect of building heating and air-conditioning that did not undergo much change in the last portion of the 20th century is the process by which thermal comfort is maintained within buildings. By and large, the industry within the United States is still dominated by conventional forced air systems with radiant systems being considered as "special application". The first costs (i.e. capital, installation etc). for radiant systems are comparable with those for traditional variable-air-volume (VAV) systems, but their lifetime energy savings over VAV systems are routinely 25% or even more[21].

4.2 History of Radiant Cooling Systems

Radiant heating and cooling has been used for thousands of years. The Romans used hypocausts in heavy masonry buildings to keep them warm during the winters in northern Europe and the Turks used stream water run through channels in walls and floors to cool their palaces during the warm summers. A common thread was the use of building mass to act as a thermal storage medium, while using radiant energy for thermal comfort.

Radiant cooling and the use of the building's thermal mass to provide off-peak cooling opportunities have been used with increasing regularity in Europe, mainly due to the high energy costs. Swiss "Batiso" buildings (Batiso = batimentisotherm, a French term for "constant temperature building") have become more common and the technology better understood over the last ten to fifteen years[25].

4.3 All-Air Systems vs. Radiant Cooling Systems

An air-conditioning system is designed to control indoor temperature and humidity, and to provide fresh, filtered air to building occupants. The majority of air-conditioning systems currently in operation are all-air systems, meaning that they employ air not only for the ventilation task, but also as a heat and humidity transfer medium.

The overall energy used to cool buildings with all-air systems includes the energy necessary to power the fans that transport cool air through the ducts. Because the fans are usually placed in the air stream, fan movement heats the conditioned air, thus adding to the thermal cooling peak load. Usibelli and collaborators[16] found that, in the typical office building, in Los Angeles, air transport accounts for 13% of the building peak cooling demand. By comparison, external loads account for 42%, lighting for 28%, people for 12%, and office equipment for 5% of the building peak cooling demand.

Computer modeling for different California climates using the California Energy Commission (CEC) base case office building show that, at the time of the peak cooling load, only 10% to 20% of the supply air is fresh air[17] Only this small fraction of the supply air is necessary to ventilate buildings to maintain acceptable air quality. The difference in volume between supply air and fresh outside air is made up by re-circulated air. The re-circulated air is necessary in all-air systems to remove excess heat from a building and maintain a comfortable indoor environment. This additional amount of supply air often causes draft, and may contribute to indoor air quality problems due to dispersal of pollutants throughout the building. Due to inefficiencies in the duct systems, recirculation also exacerbates duct air leakage and heat transfer through duct walls[18].

A radiant cooling system consists of a cooled surface and an air distribution system. The radiant cooling system employs long-wave (infrared) radiation to the cooled surface to remove unwanted heat from a space, and maintains acceptable indoor air quality and controls indoor air humidity by supplying fresh, filtered, dehumidified air through its air distribution system. In its operation as an air-conditioning system, a radiant cooling system thus separates the task of sensible cooling from those of humidity control and ventilation. More detailed operation of the radiant cooling system is discussed in the following section.

4.4 Mechanics of a Radiant Cooling system

The human body transfers heat in three different ways: radiation, convection, and evaporation. Thermal comfort is when these three factors are in thermal neutrality. Ideally 50% of body heat is cooled by radiation, 30% by convection and 20% by evaporation (sweat and breathing through the mouth). With an ideally designed conditioning system, the occupant would not know if it is cooling or heating[19].

Radiant cooling falls in the "air-and-water" category where the outside air ventilation system provides only the necessary fresh air while the hydronic thermal distribution system with a radiant heat exchanger provides the cooling. Therefore radiant cooling or heating systems address both, the convection and radiation factor of body heat whereas conventional air conditioning mainly addresses the convection factor by high air circulation[20].

With radiant systems, people are cooled by radiant heat transfer from their bodies to adjacent surfaces such as ceilings, walls or floors, whose temperatures are held a few degrees cooler than ambient (see Figure 19). Space conditioning energy is moved from chillers or boilers to radiant panels or concrete slabs using water as medium. This produces impressive savings, since water has roughly 3,500 times the energy transport capacity of air. Even accounting for the pressure drop involved in pumping water throughout a building, a hydronic system can transport a given amount of cooling with less than 5% of the energy required to deliver cool air with fans[21].

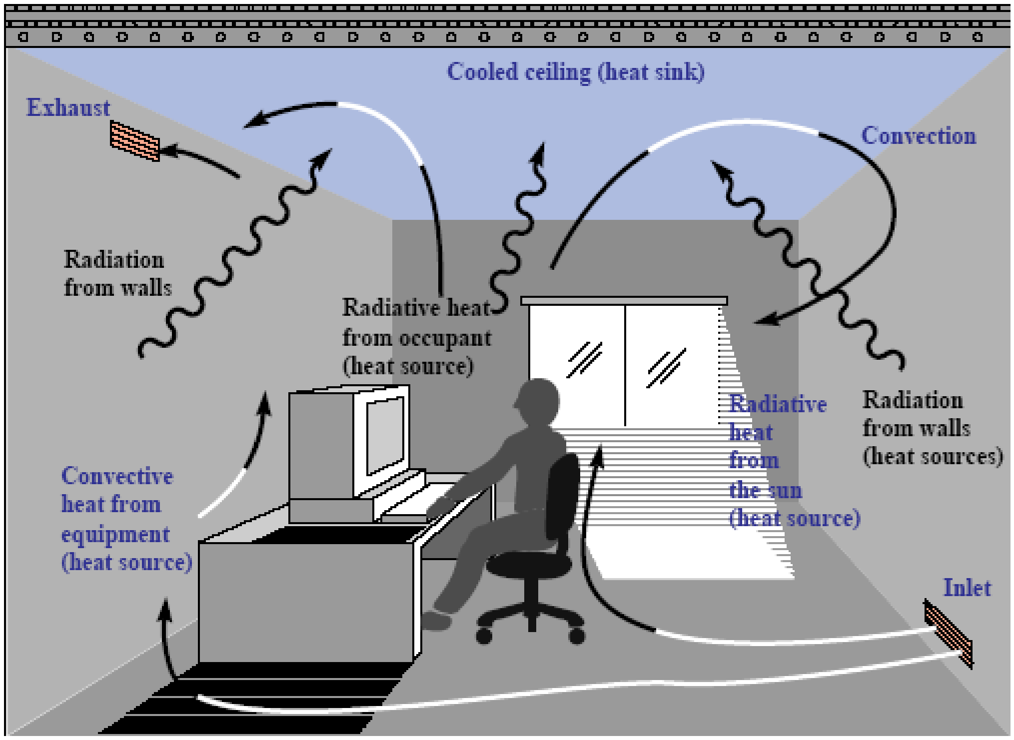


Figure 19: Air flow and heat exchange in a room with cooled ceiling

In most commercial buildings, both cooling and ventilation are accomplished by circulating large volumes of air throughout the conditioned space. This requires substantial fan power and large ducts, and it is a source of drafts and noise. With a radiant space conditioning system, the ventilation function is separate; the volume of air moved and the components to move it can be roughly 5 times smaller. Fan power is saved and ducts can be smaller[21].

In addition to substantially lowering energy and peak load costs for space conditioning and ventilation, radiant systems enjoy other advantages over VAV systems:

- Better indoor air quality (because ventilation is not re-circulated and there are no wet surface cooling coils, thereby reducing the likelihood of bacterial growth);
- Better user comfort, even at room temperatures closer to outside air temperatures, than is possible with convective space conditioning (because radiant heat transfer is direct and draft-free; also no noise is associated with space conditioning);
- Better efficiency and possibly smaller sizes of chillers and boilers (because delivery temperatures are closer to room temperatures);

- Lower maintenance cost (because of inherent system simplicity – no space conditioning equipment is needed in outside walls, and a common air system can serve both interior and perimeter zones)[21].

4.5 Radiant System Economics

Figure 20 shows how radiant cooling systems achieve energy savings. The graphic breaks out the components of peak energy use in California office buildings for a conventional system and for a radiant cooling system that uses water as an energy transport medium[21]. About 62.5% of the conventional system's energy use consists of cooling load that the chiller must remove. Virtually all the remaining power demand is used for air transport, and radiant cooling can eliminate most of that. The hydronic radiant system reduces peak power demand by pumping chilled water to provide radiant cooling, rather than by blowing chilled air. The cooling load from lights decreases because the radiant system's 100% outside air ventilation directly vents half of the lights' heat to the outdoors. In conventional systems, most of that heat stays in the building with re-circulating supply air. As a consequence, in the example shown in the Figure 20, energy savings is greater than 42 percent. In areas with high humidity during the cooling season, the savings are proportionally less[21].

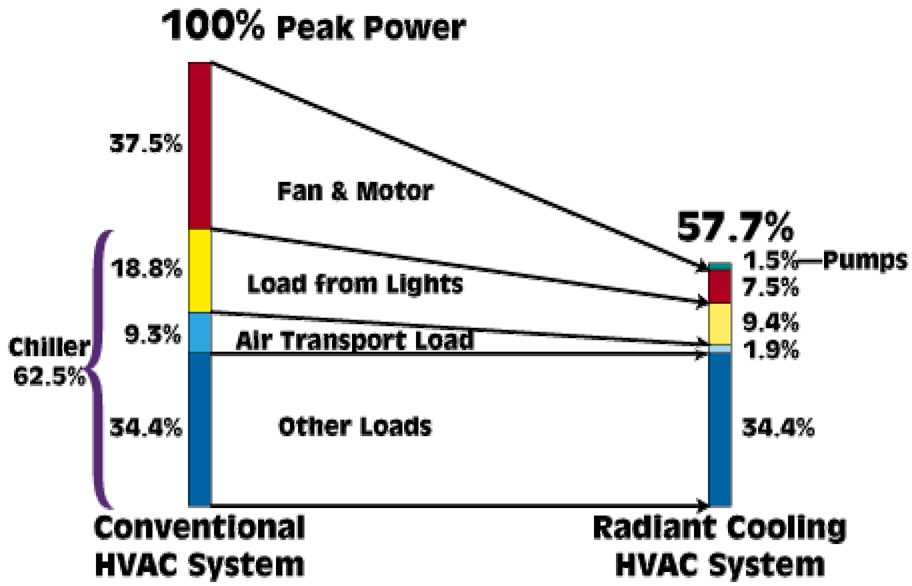


Figure 20: Peak Power Demand for Conventional and Radiant Cooling

Corina Stetiu of Lawrence Berkeley National Laboratory (LBNL) ran detailed simulations of the same prototypical office building located in eleven U.S. cities, comparing the performance of radiant cooling systems with ventilation and conventional "all-air" VAV systems. In comparison with VAV systems, she found that on average, the radiant cooling systems save 30% on overall energy for cooling. Energy saved ranges from 17 percent in cold, moist areas to 42 percent in warmer, dry area[22] (The primary reason for lower savings in humid areas is that substantial dehumidification must be employed by both systems. Therefore, the ratio of energy savings to total energy is smaller.).

Of course, initial capital costs as well as energy costs are important in considering radiant cooling for a new building. According to Sean Timmons, a senior mechanical engineer with Arup and Partners in San Francisco, buildings with radiant cooling systems routinely show slightly lower first costs but substantially lower lifecycle costs than systems with four pipe fan coil units[23] using current German prices. Franc Sodec, an engineer with Krantz-TKT in Aachen, Germany, ran simulations that show up to 20 percent savings in first costs by radiant cooling systems with ceiling panels versus standard VAV systems when the panels are designed to supply about 14 to 18 Btu per square foot of cooling[24]. He also reports 40 to 55 percent savings in space requirements owing to lesser ducting.

There are currently three different hydronic radiant cooling systems available. The panel system (See Figure 21) is the most common radiant system. The panels, usually aluminum, can be surface mounted or embedded on floors, walls or ceilings. The capillary tube system (see Figure 22) characteristics are small closely spaced tubes that are embedded in plastic, gypsum, or mounted on ceiling panels. The many tubes allow for better heat absorbing distribution and a thinner ceiling. And, finally, the concrete core conditioning systems (see Figure 23) with tubes embedded in a concrete slab allows for peak load shifting because of its thermal storage capacity. This could be used also as a wall mass. In each of the systems, water is mixed in a glycol solution and cooled by an air-to-water heat pump, a cooling tower, a ground source heat pump, or even well water. Since the radiant surface is typically a whole floor or ceiling surface, the water can be as warm as 65ºF. Figure 24 compares the different types of radiant cooling systems.

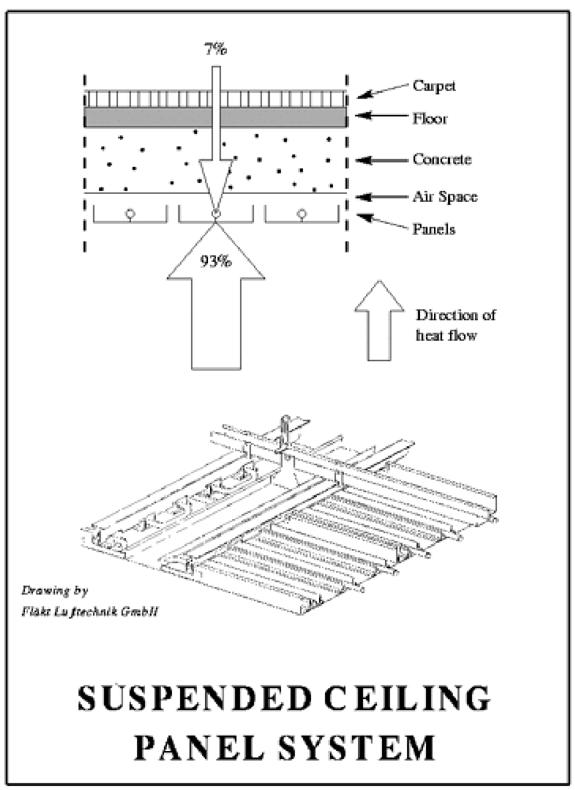


Figure 21: Suspended Ceiling Panel System

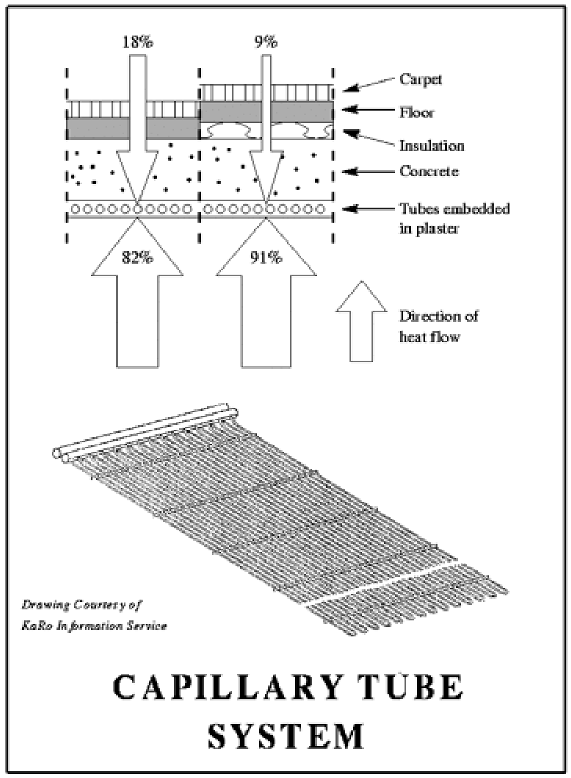


Figure 22: Capillary Tube System

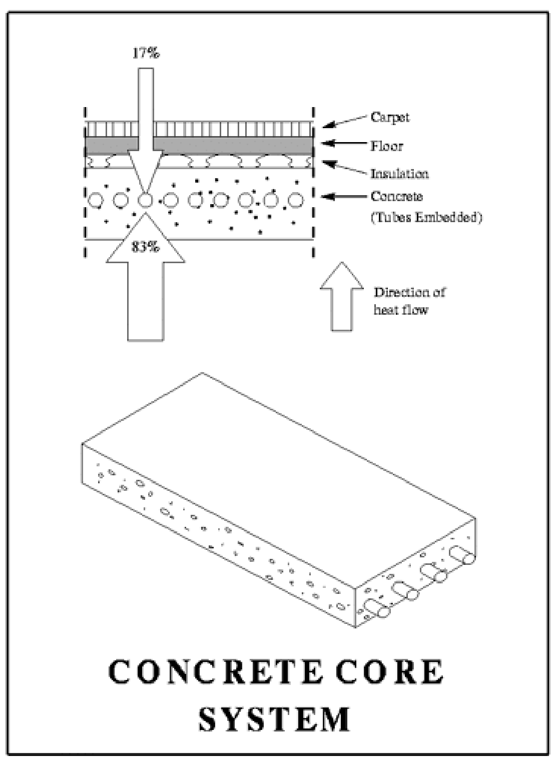


Figure 23: Concrete Core System

Table 1: Radiant cooling systems compared

The table below compares the three principal types of hydronic radiant cooling systems and the convective panel system.

System	Locus	Retrofit?	Initial cost	Efficiency	Peak shave?	Controls	Maintenance
Concrete core	Floors, ceilings	Not easily	Lowest	Excellent	Best	Large zones, slow	Lowest
Cool grids (tubes in gypsum)	Ceilings, walls	Yes, ceilings	Medium	Good	Good	Small zones, slow	Low
Metal panels (hydronic)	Ceilings, walls	Yes, ceilings	Medium	Good	Good	Small zones, fast	Low
Metal panels (convective)	Ceilings	Yes	Low	Fair	Poor	Large zones, fast	Medium

Figure 24: Radiant Cooling systems compared (Source: Energy Design Resources)

The key to making use of a radiant cooling system is the building envelope. The perimeter solar gains and thermal transmission loads must be reduced to as low as possible to allow the radiant cooling system to operate properly. Radiant cooling capacity is limited by the cooling surface temperature being just above the dew point of the ambient air in the space to be cooled. This means that the minimum effective temperature of the radiant cooling surface in most building applications is around 16degC (61degF) to avoid the forming of condensation. The total cooling capacity of a radiant surface at that temperature is around 80 watts/sq.-m (25btu/hr/sq-ft.), the corollary of that is that the building interior heat gain should be kept below 80 watts/sq-m (25btu/hr/sq-ft.) for the radiant cooling system to be effective. That's where the high performance building envelope comes into play[25].

4.6 Drawbacks of the Radiant Cooling System

According to Mark Linde, a principal of a Canadian manufacturer of several lines of hydronic radiant panels, the technology is intriguing to engineers and academics in North America. But when it comes to putting up new buildings, traditional VAV approaches usually hold sway in part because the perception that radiant cooling systems have higher first costs still appears to be widespread. Mark Lande believes that "most buildings in North America are built with not enough thought about comfort or energy bills, developers just want to build them at the lowest first cost possible"[21].

There are two main reasons why designers hesitate to embrace the technology. First, there's the reluctance to be a pioneer. Promoters hope to surmount this barrier by showcasing a wide range of successfully radiantly conditioned buildings in Europe. For example, Hewlett Packard has a new facility in England that company officials like so well they plan to include its radiant cooling features in their next buildings in the U.S. Second, there was moisture problems with some systems built several decades ago. To avoid condensation, radiant ceilings must be maintained several degrees warmer than the dew-point. The challenge is to be able to sense the dew-point temperature with some precision and adjust incoming water temperature to achieve effective cooling while avoiding condensation. In the past decades, there were no sensor or control technologies to solve this problem very well. Manufacturers were also unable to achieve uniform thermal bonding between the water-bearing copper tubing and the metal ceilings. This resulted in lowered cooling efficiency and cold spots, which could cause condensation. Currently, these technical problems appear to be satisfactorily resolved. Modern sensors in combination with direct digital controls (DDC) enable fast, accurate tracking and adjusting to optimize the cooling function while avoiding condensation problems. Further, manufacturers now use special fixtures in combination with reliable heat conducting tapes or compounds to ensure good heat transfer between tubes and metal plates.

The warm, moist air infiltrating into any air-conditioning building poses a problem that requires energy to solve it. The best approach in any climate is to build tight buildings and control air flow. The strategy employed with radiantly cooled buildings is to keep ventilation rates as low as possible consistent with maintaining high indoor or air quality while relying on dehumidifying ventilation air to keep the dew-point low[21].

4.7 Dana Building Radiant Cooling System

The Dana Building has a radiant air conditioning system, as opposed to a traditional forced-air system, or the even less efficient wall-unit air conditioners. Prior to the renovation, there was no air conditioning system in the building, but an air-conditioning system was considered in the renovation project to increase comfort levels within the building. To be consistent with the theme of the renovation, “Greening of Dana”, the conventional forced air systems were rejected and alternative energy efficient technologies were investigated.

Radiant Cooling panels are used in the non-laboratory spaces on the ground floor through third floors. In the radiant cooling system, cold water runs through copper pipes at the ceiling level. There are metal shrouds that cover the pipes. The cold water acts as a heat sink for the warm air in the room, thereby replacing the air in the traditional forced air system. This translates into substantial energy savings in the building, as water is about three times more efficient than air as a heat transfer medium.

4.7.1 Alternative HVAC System Options considered

Ove Arup & Partners, consulting engineers for the Dana renovation project proposed three options for the HVAC renovation of Dana building for initial costing comparison purposes.

- Chilled Ceiling / Chilled Beam radiant cooling for classrooms and open office areas in combination with VAV for cooling/heating of offices
- All air VAV cooling / heating system with small, local, floor by floor plant
- Refurbishment of existing fan-coil units and extension of this type of system to offices and areas of building not presently served by HVAC

All of the above assume the existing heating and chilled water distribution pipe work on each of the floors remains.

4.7.2 System Comparison by consulting engineers, Ove, Arup & Partners

Table 2 compares these options in a matrix showing the pros and cons of each system. Some design components will have a positive effect on the building spaces regardless of HVAC system chosen. The first of these is insulating the exterior walls of Dana. In separate analyses performed by the design team, insulating the walls improves both the internal thermal comfort for occupants as well as the energy performance of the building. Another design component that would have a positive effect on all HVAC systems is the proposed exterior shading. Shading would help reduce summer cooling loads and would both improve occupant thermal comfort and reduce energy consumption.

Table 2: Comparison of the different systems proposed for the Dana Building

System	Pros	Cons
Dist'd Fan Coils Central Makeup	- High degree of local control	- Currently installed system has proved to be noisy and is unused by building occupants - Inefficient inherent in many small motors - Difficult to maintain (Filter replacements etc.)
Floor-by-Floor All Air System	- Easy to maintain - Preferred campus system for new construction – existing expertise in operation/maintenance	- Duct size may need to be increased to provide adequate air to all rooms. - Lose programmatic space on each floor
Combined Chilled Ceiling/Beam and Air Systems	- Very quite - Efficient system (water is a better heat transfer medium than air and higher air temperatures are still comfortable due to radiant cooling - Comfortable heating and cooling – no drafts - Minimum space requirements - Works well with operable windows - Reuse existing piping loops	- Possible humidity control problems – especially with relation to existing building envelope - Slightly more complex building controls required - Poor performance history (but there are new installations that look good)

4.7.3 System Recommendations by Ove Arup & Partners

Based on the consultants' experiences on successful implementation of chilled ceiling systems, they believed the combined chilled ceiling and air system represented the option that best meets the programmatic requirements for Dana Building. To help ensure the success of this system, they recommended upgrading the building envelop to include a vapor barrier and insulation.

This recommendation is based partly on quantitative analyses and partly on experience and judgment. It does not come as the result of comprehensive building modeling and life-cycle costing. In order to forward this option as the system of choice, further analysis relating to energy consumption, estimation of system cost, and exploration of system design issues was performed.

If for some reason the combined chilled-ceiling/air-system option was not acceptable to all parties on the design and client teams, then they would have recommended the use of the floor-by-floor all-air system option. This more conventional system has proven benefits and is the default preferred choice for new construction on the University of Michigan campus. Figures 25 and 26 show the radiant cooling system installed in the Dana Building.

Figure 25: Copper Pipes in the Radiant Cooling System at S.T. Dana Building

Figure 26: Installed Radiant Panels at S.T. Dana Building

4.7.4 Mechanical System Overview of the Renovated Dana Building by Ove Arup & Partners

The heating, cooling, and ventilating system for the Dana Building Phase II renovation consists of reconfigured existing systems overlaid with a new chilled ceiling system for Ground floor through the third floor, and a new variable volume air system for floor 4. For Ground floor through the third floor, the existing air handling unit (AHU-1) on the fourth floor and its distribution system will be reconfigured to provide all of the ventilation requirements and part of the heating and cooling requirements. This unit is a 100 percent outdoor air unit. The additional heating requirements will be met by reconfiguring the existing hydronic baseboard heating system. Installing a new chilled ceiling system will provide the additional cooling requirement.

For floor 4, a new air handling unit (AHU-2) and air distribution system will be provided to meet the ventilation, heating, and cooling requirements for this area. Adding a new water distribution loop will provide chilled water for radiant cooling panels. This loop will run at approximately 60°F. It will use the main chilled water return as its primary source resulting in a very energy-efficient arrangement. As there will still be some fan-coils within the building from the Phase I work, it will be necessary to keep the existing piping loops at 45°F supply and 57°F return.

To prevent condensation on the chilled ceiling panels, the supply air from AHU-1 must be significantly dehumidified. To accomplish this, a second cooling coil will be added to the existing configuration. To reduce the energy impact of this additional dehumidification, a U-Tube heat recovery system will be installed as well.

Additionally, a desiccant dehumidifying unit may be cost-effective. It would be installed on the common outdoor air intake for AHU-1 and AHU-2. Steam would be used for regenerating the desiccant.

The outdoor air system for the Ground floor through the third floor will be variable volume. Variable air volume (VAV) air terminal boxes will distribute ventilation through the spaces. Providing a variable volume system will save energy and accounting for diversity in building occupancy makes the current size of AHU-1 feasible. Supply air will be introduced through ducted ceiling or wall diffusers. Air will be returned via ceiling grilles.

With the continued use of operable windows in the space, natural ventilation will be realized when the windows are open. This natural ventilation may potentially cause a condensation problem on the chilled ceilings/beams if windows are opened when it is very humid outside. To avoid this problem, occupants will need to be educated about proper system operation. An occupant feedback system will be established that will inform occupants of correct building operation on a day-by-day, or seasonal basis.

The laboratories containing fume hoods in the basement are being upgraded with new VAV fume hood controls (Phoenix System) as part of the Phase I work. Where fume hoods are installed on floors 1 through 3, Phoenix VAV air valves will be installed on supply and exhaust ducts. The rooms will be maintained at negative pressure with a minimum air change rate of 10 air changes per hour when occupied. The exhaust air ducts from Phase II laboratories will connect into the existing Phase I fume exhaust system.

4.7.4.1 Mechanical System Controls

A modular direct digital control (DDC) system will be used for the HVAC system. Standalone modules will control air handlers, pumps, etc. Zone controls (terminal boxes, thermostats, reheat coils, etc.) will use pneumatic or electric actuators. The system will be capable of transferring data to the existing campus energy management control system for monitoring purposes only.

Each zone will have a minimum of one dedicated zone temperature sensor. Each zone will also have a relative humidity sensor and CO_2 sensor. All sensors will report to the building management system (BMS).

Relative humidity and CO_2 sensors require yearly maintenance to maintain their accuracy. Relative humidity sensors typically drift 0.5 percent per year. CO_2 sensors drift typically 0.2 percent per year. Yearly maintenance for these sensors takes between 5 and 10 minutes per sensor and consists of using a manufacturer-supplied calibration unit to check sensor readings and adjust sensor as needed.

To provide a level of safety, the zone relative humidity sensors will be monitored for high humidity conditions and control two levels of space humidity protection. First, a high-humidity state will trigger the outdoor air VAV boxes to maximize the outdoor air rate. If this does not reduce the humidity enough, the chilled ceiling cooling loop will be disabled.

5 BUILDING ENERGY MODEL

5.1 Building Model

The eQUEST™ energy modeling software allows for a graphical display of all the 3-dimensional geometry entered in the application to describe the building. Figure 27 is a screen shot from eQUEST™ of the S.T. Dana Building model.

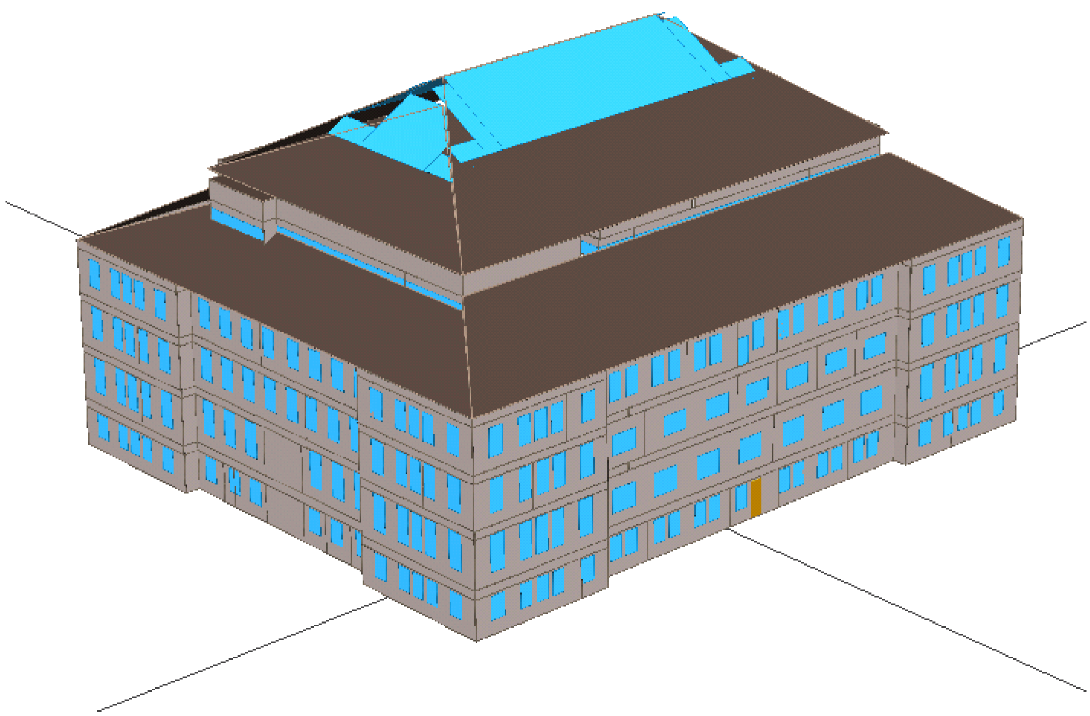


Figure 27: Isometric view of the S.T. Dana Building Model in eQUEST™

As is clear from the screen capture above, a special effort was made to model the building in detail to improve the accuracy of the analysis work. The details of the building energy model are listed in the sections below.

5.2 Energy Modeling Description

The energy model for the S.T. Dana Building was built using the eQUEST™ interface version eQUESTv3-16-to-18_Updata_03-02-25.exe which employs the DOE-2 engine version DOE-B22D38g. The weather file used in this simulation is Detroit.tmy2 which is the standard for Detroit, the closet weather file that matches the weather in Ann Arbor.

5.3 Building Geometry

In order to improve the accuracy of the modeling effort, the amount of simplification made to the building geometry for zoning was kept to a minimum. Typically, there are a large number of simplifications made in the zoning of a building between the real design and the energy model representation. In this model, the true zoning of the building was used to a great extent. The images below indicate the zoning used for the S.T. Dana Building. Figures 28 through 32 show the floor plans as modeled; this is very close to the actual floor plans after the renovation of the Dana Building.

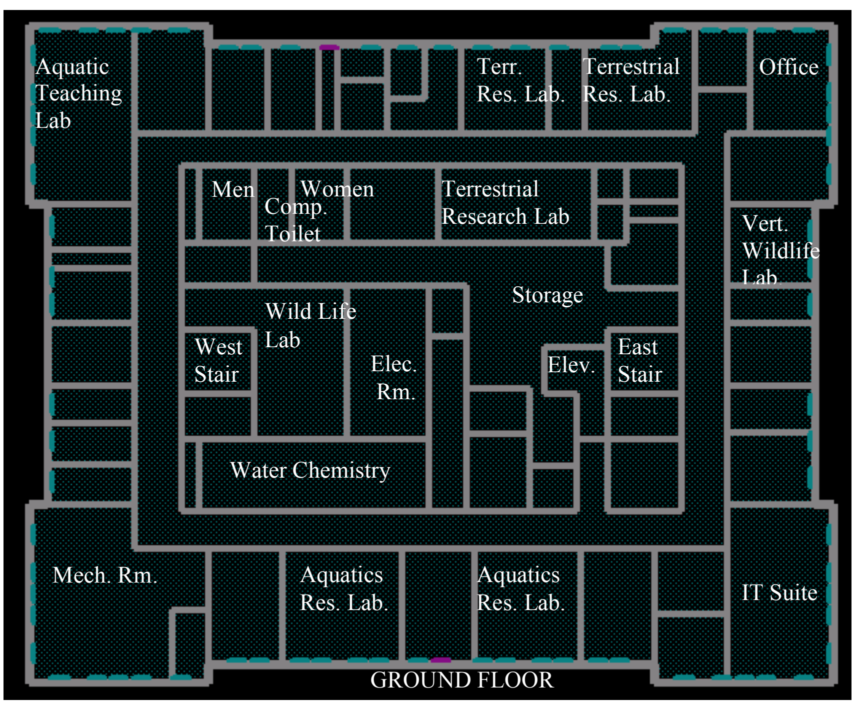


Figure 28: Ground Floor

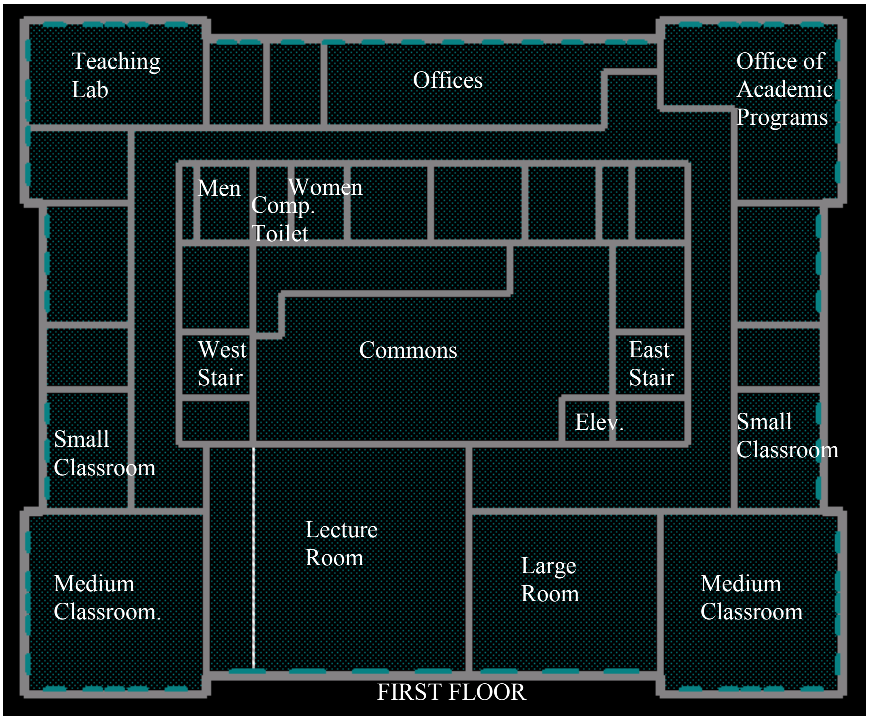


Figure 29: First Floor

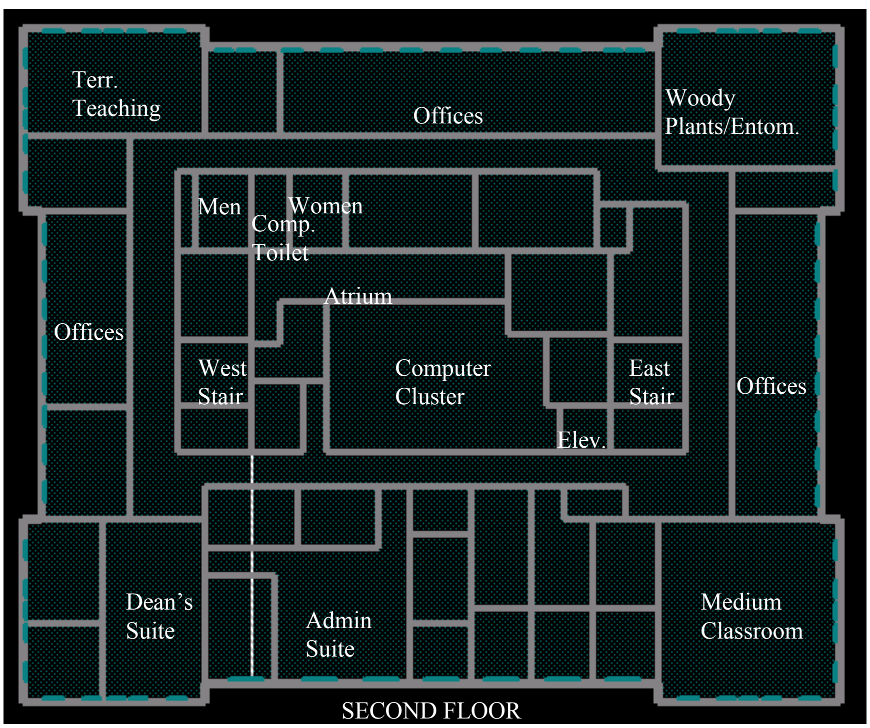


Figure 30: Second Floor

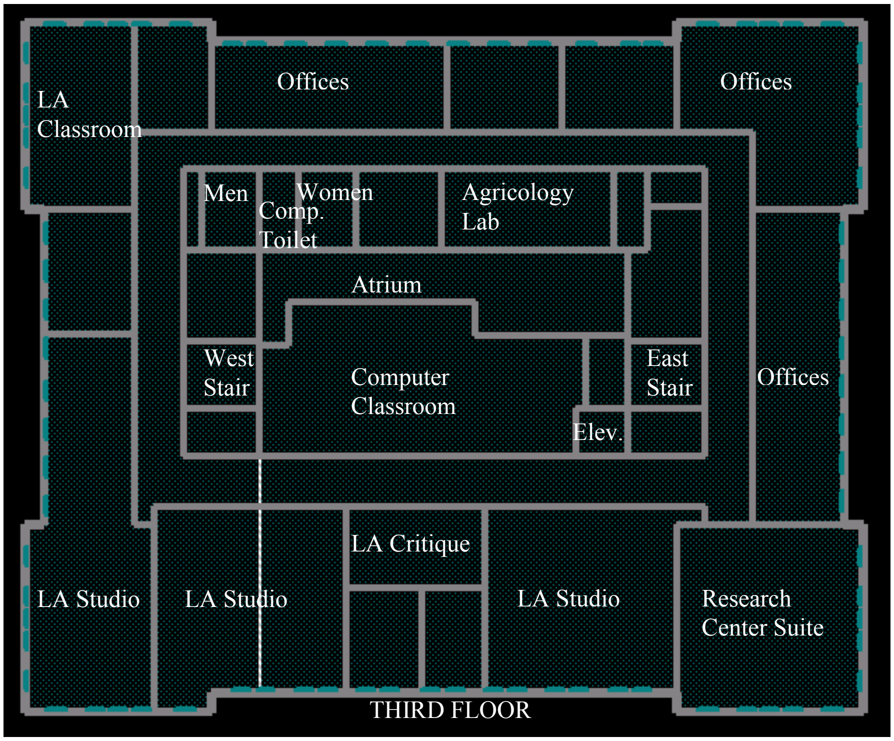


Figure 31: Third Floor

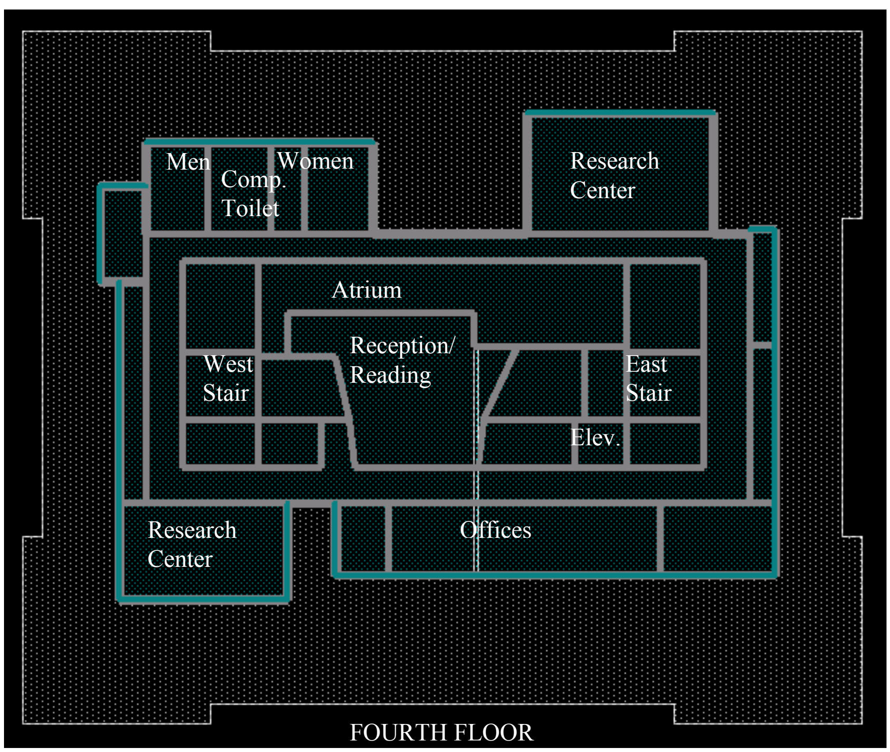


Figure 32: Fourth Floor

5.4 Model Inputs

5.4.1 Building Opaque Envelope

The building envelope (includes exterior and interior walls, basement floor, ceiling and roofs) is a medium through which heat flows in and out of the building. The energy transfer through the building envelope depends on the temperature differential between the exterior and interior of the building envelope, and the thickness and material composition of the building envelope. Energy loss calculations through the building envelope require the thermal resistances (U-values) of the different components of the opaque building envelope to be as close as possible to the actual U-value of the building envelope. The opaque wall surface constructions are described in the Table 3.

Table 3: Building Envelope Description

Wall Type	Composite U-Value (Btu/hr-ft2-degF)	Materials	Equivalent Insulation
Exterior Wall	0.088	Stone 21in, Air layer <3/4in, MinWool Batt R7, GypBd 5/8in	11.4 R-value
Interior Wall	0.107	GypBd 5/8in, MinWool Batt R7, GypBd 5/8in	9.4 R-value
Interior Wall (Atrium)	0.098	GypBd 5/8in, Air layer <3/4in, MinWool Batt R7, GypBd 5/8in	10.2 R-value
Basement floor	0.079	Insul Bd 3in, Soil 12in, Conc. HW 8in, Felt 3/8in	12.7 R-value
Floor	0.746	CMU HW 6in ConcFill	1.3 R-value
Ceiling	1.75		0.6 R-value
Roof	0.072	Steel Siding, Airspace, MinWool Batt R11, GypBd 5/8in	13.9 R-value

The roof is modeled with a 0.7 absorbtance. The ground floor and the first floor windows are set back by one foot, the second floor windows are set back by 9 inches and the third floor windows are set back by 6 inches.

5.4.2 Glazing

Windows and their associated glazing are required for light and air but they are also a significant medium of heat loss from the building. The glazing properties are summarized in Table 4.

Table 4: Glazing properties

Location	Category	DOE-2 Glass
Glazing on Gd, Ist, 2nd, 3rd & 4th floor windows	Glass Library Code	2003
	Glass U-value	0.56
	Glass Shading Coefficient (SC)	0.81
	Glass SHGC	0.69
	Glass Visible Light Trans. (VLT)	0.78
Atrium Glazing	Glass Library Code	2636
	Glass U-value	0.43
	Glass Shading Coefficient (SC)	0.45
	Glass SHGC	0.39
	Glass Visible Light Trans. (VLT)	0.44

The glass from the DOE-2 component library with type code 2003 and 2636 is used to model the actual glass that is used in the building because the glass in the DOE-2 library contains detailed physical properties that are difficult to replace from manufacturer catalogue data. PV panels were proposed over the atrium glass, but they were not included in the model; instead the shading coefficient of the glazing has been increased to compensate for the shading that the PV panels would provide.

5.4.3 Building Areas

Table 5 shows a breakdown of the floor area modeled for different use types in the Academic Building.

Table 5: Building Areas

Space Type	Area	
	(ft^2)	(%)
High Density Classrooms	1,365.0	1.3
Low Density Classrooms	25,032.6	23.9
Teaching Labs	2,170.0	2.1
Research Labs	15,203.5	14.5
Offices	26,060.3	24.9
Miscellaneous (Toilets, corridors, stairs etc.)	9,779.4	9.3
Service (Electrical, mechanical etc.)	25,136.0	24
Total	104,746.8	100

The total area modeled represents the conditioned area that is relevant to DOE-2 energy calculation engine. The gross square footage of the building per University of Michigan calculations is 105,000 square feet.

5.4.4 Occupancy

Occupants in the building require appropriate heating and cooling but depending on the occupancy size can be sources of heat energy themselves. Table 6 summarizes the occupancy inputs for the energy model:

Table 6: Occupancy Schedule

Space Type	Base Occupant Density [ft^2/person]	Maximum Diversity	Schedule Summary
High density classrooms	20	90%	7am – 9pm
Medium density classrooms	50	90%	7am – 9pm
Teaching Labs	50	90%	7am – 9pm
Research Labs	100	90%	7am – 9pm
Offices	150	95%	7am – 9pm
Miscellaneous (Toilets, corridors, stairs etc.)	500	30%	7am – 9pm
Service (Elec., mech. etc.)	1000	50%	7am – 9pm

5.4.5 Lighting

Lighting is a major source of heat energy inside the building. The lights especially the incandescent lamps emit significant heat energy and increase the load of the cooling systems in the building. Table 7 summarizes the lighting inputs for the energy model.

Table 7: Lighting Schedule

Space Type	Base Lighting Density [Watt/ft^2]	Maximum Diversity	Schedule Summary
High density classrooms	1.5	95%	7am – 9pm
Medium density classrooms	1.5	95%	7am – 9pm
Teaching Labs	1.75	95%	7am – 9pm
Research Labs	1.75	95%	7am – 9pm
Offices	1.5	90%	7am – 9pm
Miscellaneous (Toilets, corridors, stairs etc.)	1	95%	7am – 9pm
Service (Elec., mech. etc.)	1	30%	7am – 9pm

5.4.6 Equipment

Equipment includes computers, printers, microwave ovens, refrigerators, toasters. They emit heat energy but to a lesser extent than lighting. Table 8 summarizes the equipment inputs for the energy model

Table 8: Equipment Schedule

Space Type	Base Equipment Density [Watt/ft^2]	Maximum Diversity	Schedule Summary
High density classrooms	0.5	90%	7am – 9pm
Medium density classrooms	0.25	90%	7am – 9pm
Teaching Labs	2	90%	7am – 9pm
Research Labs	4	90%	7am – 9pm
Offices	1	95%	7am – 9pm
Miscellaneous (Toilets, corridors, stairs, elevators etc.)	0.25	30%	7am – 9pm
Service (Elec., mech. etc.)	0.25	50%	7am – 9pm

5.4.7 Domestic Hot water Demand

Domestic hot water consumption is assumed to be the same in the base-case and proposed model and therefore has not been modeled.

5.4.8 HVAC Systems

The Base Model has 5 HVAC systems. They are roughly named according to the areas they serve. They are the Fourth Floor Variable Air Volume (VAV), Ground Floor VAV, Outdoor Air (OA) System, Dana Fan Coil and the General VAV. The Proposed Model has exactly the same systems except that the general VAV system is replaced by the Radiant Cooling System.

5.4.8.1 System Setup

Table 9 describes key parameters for the different HVAC system setup.

Table 9: HVAC System Setup

HVAC SYSTEM SETUP						
HVAC Systems	**Fourth Floor VAV**	**Ground Floor VAV**	**OA System**	**Dana Fan coil**	**General VAV**	**Radiant Cooling System**
System Type	Variable Air Volume	Variable Air Volume	Variable Air Volume	Fan Coil	Variable Air Volume	Fan Coil
Supply CFM	11,000	20,000	n/a	n/a	11,000	n/a
Min. Supply Temperature	55ºF	65ºF	55ºF	55ºF	55ºF	55ºF
Max. Supply Temperature	75ºF	75ºF	70ºF	105ºF	75ºF	105ºF
Supply Fan Schedule	6am – 9pm	6am – 9pm	6an – 9pm	6am – 9pm	6am – 9pm	6am – 9pm
Supply Fan kW/CFM	0.00109	n/a	0.00109	n/a	n/a	0.0000
Supply Fan Delta	3.37	n/a	3.37	n/a	n/a	0
Supply Fan Control	Variable Speed	Variable Speed	Variable Speed	n/a	Variable Speed	n/a
Economizer Type	Air-side	Fixed Fraction	Fixed Fraction	n/a	Dual Temperature	n/a
Supply-Air Temp. Control	Warmest	Warmest	Constant	n/a	Warmest	n/a
Reset Priority	Airflow First	Airflow First	n/a	n/a	Airflow First	n/a
Chilled-Water Valve Type	Two way	Two – Way	Two-Way	Two-Way	Three Way	Two-Way
Chilled Water Coil ΔT	10ºF	10ºF	10ºF	10ºF	10ºF	10ºF
Chilled Water Coil Head	15ft	15ft	15ft.	15ft.	15ft.	15ft.

5.4.8.2 System Parameters

Each zone setup is described in Table 10.

Table 10: System Parameters

Zone setup	Fourth floor VAV	Ground floor VAV	OA system	Dana Fancoil system	General VAV system	Radiant Cooling system
Thermostat Type	Reverse Action	Reverse Action	Reverse Action	Reverse Action	Reverse Action	Reverse Action
Throttling Range	0.1ºF	0.1ºF	0.1ºF	0.1ºF	0.1ºF	0.1ºF
Outdoor Air	15 cfm/person	15 cfm/person	15 cfm/person	15 cfm/person	15 cfm/person	15 cfm/person
Min. Flow Ratio	0.15	0.25	0.15	0.15	0.15	0.15
Cooling Setpoint	75ºF	75ºF	75ºF	75ºF	75ºF	78ºF
Cooling Setback	80ºF	75ºF	80ºF	80ºF	80ºF	80ºF
Heating Setpoint	70ºF	70ºF	70ºF	70ºF	70ºF	70ºF
Heating Setback	65ºF	70ºF	65ºF	65ºF	65ºF	65ºF

5.4.8.3 Zone Setup

The floor plans below (Figures 34-38) indicate the areas in the S.T. Dana building served by the different HVAC systems. Figure 33 is a key to identify the areas served by the HVAC systems.

KEY	
	Fourth FloorVAV
	Ground Floor VAV
	OA System
	Dana Fancoil
	General VAV/Radiant Cooling System

Figure 33: Key to locate mechanical systems in floor plans

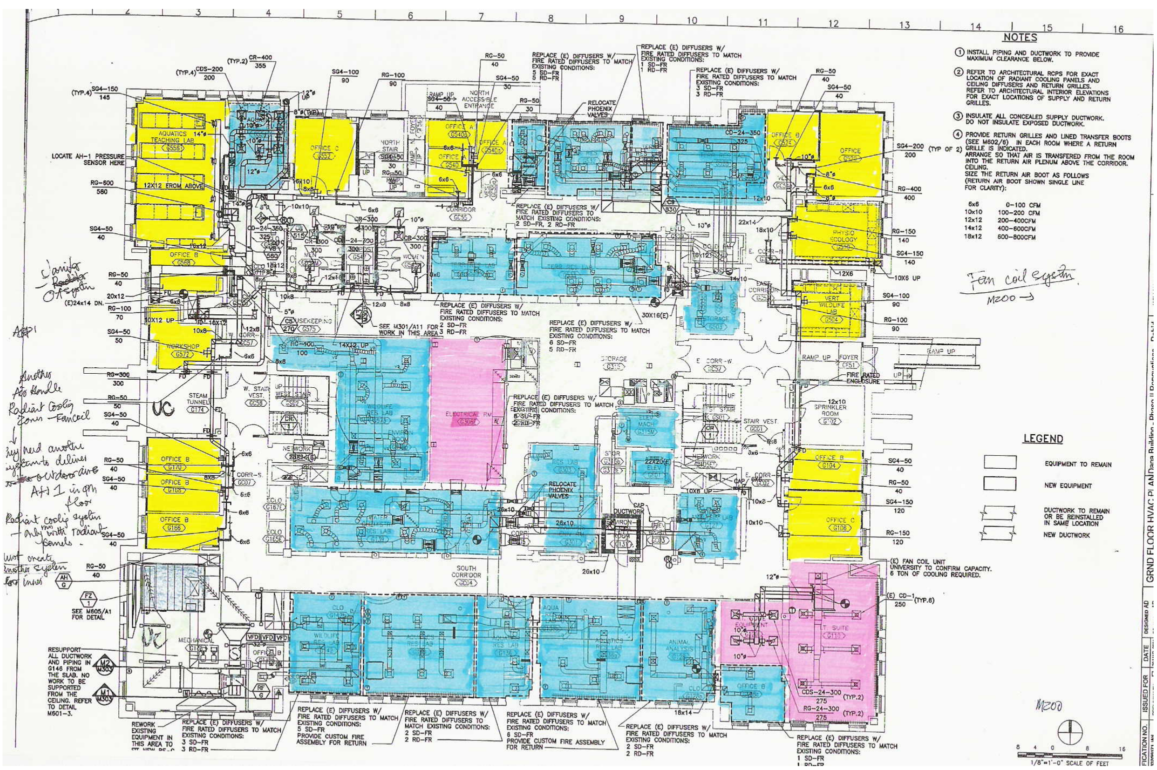


Figure 34: Ground Floor

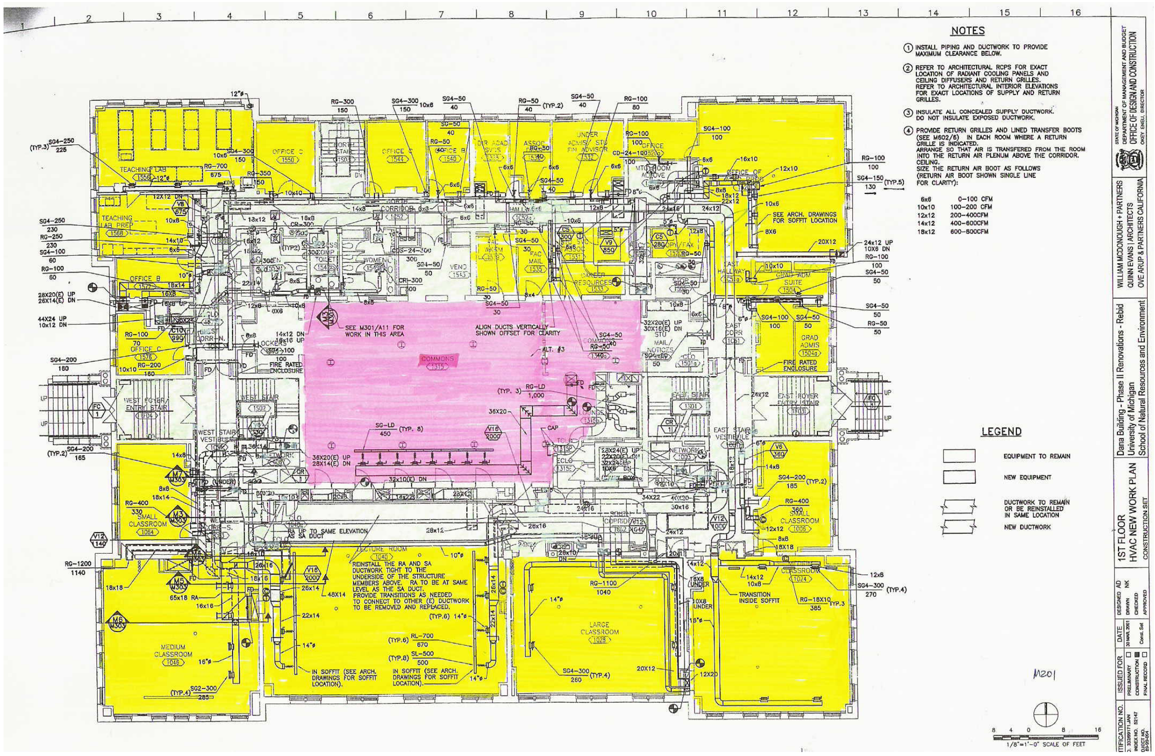


Figure 35: Second Floor

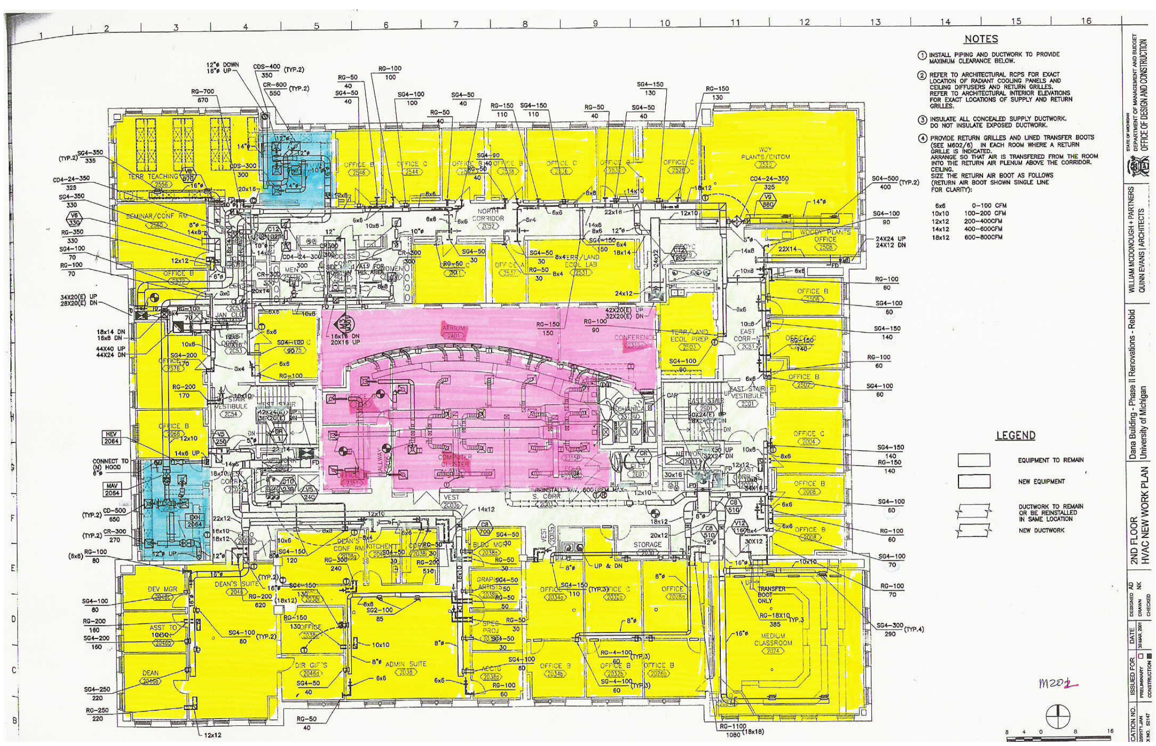


Figure 36: Second Floor

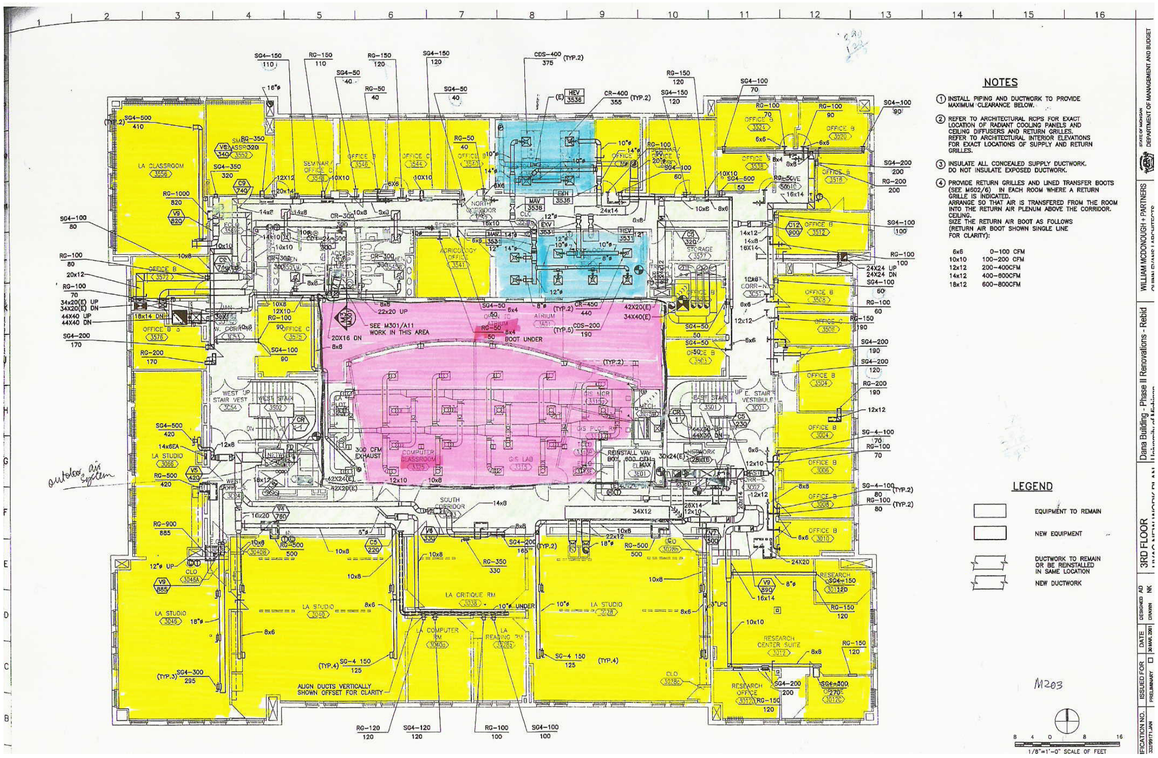


Figure 37: Third Floor

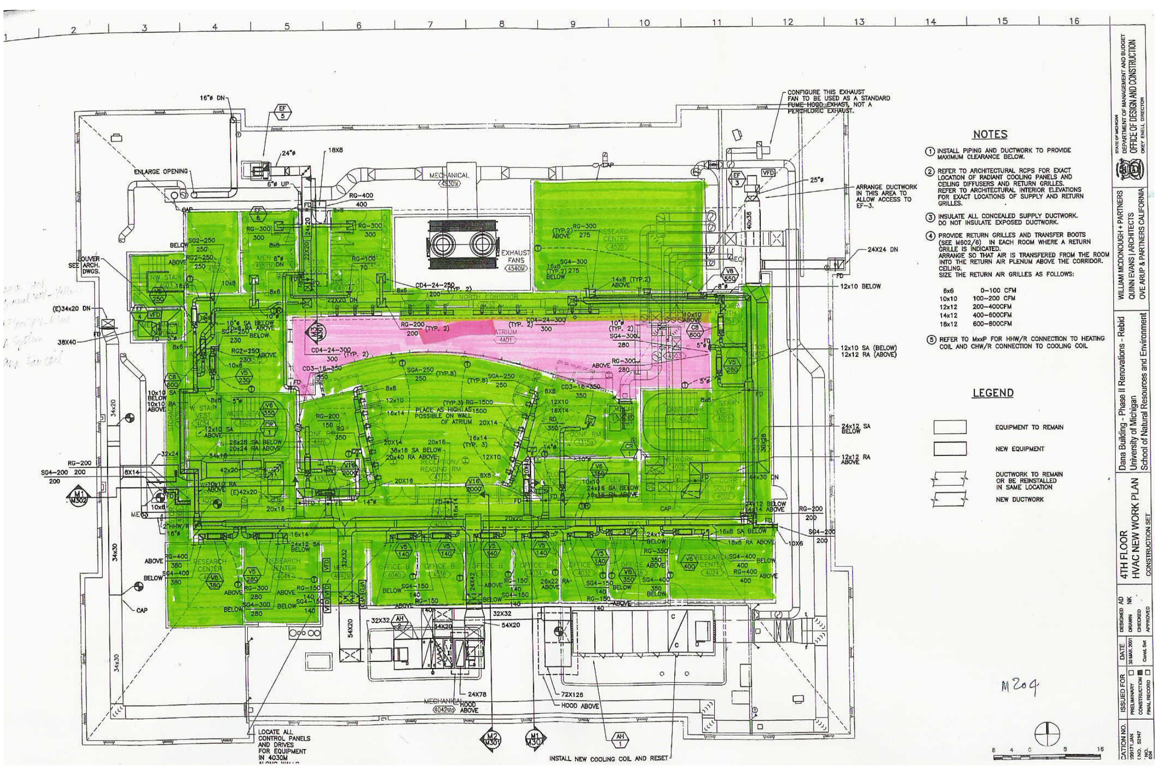


Figure 38: Fourth Floor

5.4.9 Building Water Distribution Loops

There are two primary loops, the Chilled-Water loop and the Steam loop. The radiant cooling chilled-water loop is an offset from the chilled-water loop and the hot-water loop is an offset from the Steam loop. Both the heating water and the chilled water distribution loops in the building are modeled as variable flow systems including variable speed drives on the pumps and 2-way valves on all coils.

The chilled-water loop is modeled with a 25ºF ΔT with a set-point temperature of 40ºF. Supply temperature is reset based on zone load. Loop pressure is reset based on valve position. Pumps are modeled with a 77% mechanical efficiency and premium efficiency motors.

The heating-water loop is modeled with a 40ºF ΔT with a set-point temperature of 180ºF. Supply temperature is reset based on zone load. Loop pressure is reset based on valve position. Pumps are modeled with a 77% mechanical efficiency and premium efficiency motors.

5.4.10 Plant Energy Model

Although the Dana Building is served by a Central Plant common to all the buildings on the campus, only site energy has been used for the models in the LEED^{TM} analysis. This means that the steam and electricity metered at the Dana Building by the Utilities & Plant Engineering and their associated utility costs are only considered for the model. The upstream primary energy at the Central plant is not within the scope of this project. Chilled water is provided by the absorption chillers on campus. Chillers and associated systems (cooling towers, valves, pumps, and controls) are also not within the scope of this project.

6 UTILITY RATES

Table 11: Basic Utility Rates (Source: Utilities & Plant Engineering, University of Michigan)

BASIC UTILITY RATES	
Electricity	\$0.082/kWh
Steam	\$9.77/Mbtu
Chilled Water	\$19.58/Mbtu

6.1 Electricity

Table 11 shows the utility rates used in the model for LEED^{TM} credit evaluation. The electricity utility rates are based on the current University of Michigan primary distribution rates plus the energy procurement surcharge. The rate is summarized below. There are no peak demand charges for electricity. The University of Michigan Central Plant provides electricity to the S.T. Dana Building. Utilities & Plant Engineering charges a uniform energy charge of \$0.082/kWh.

6.2 Steam

Utilities & Plant Engineering's steam utility rates are set at \$9.77/Mbtu.

6.3 Chilled Water

The S.T. Dana Building also uses Chilled Water which is provided to the Dana Building from the East University Chiller. The electricity and steam consumed by the East University Chiller is charged based on the percentage of the chilled water each building uses. This is metered by the Building Automation Services (BAS) department. Though the Utilities & Plant Engineering, University of Michigan does not charge for the chilled water directly, the unit cost chilled water was calculated recently in November 2003, by Bill Verge, Director of Utilities & Plant Engineering at the University of Michigan.

7 ENERGY ANALYSIS RESULTS

7.1 LEED™ Base Case & Proposed Case Model Description

The LEED™ computer models, the LEED™ Base Case Building and the LEED™ Proposed Building are modeled based on ASHRAE 90.1 methodology. The inputs include building envelope, occupancy, lighting, equipment and HVAC (Heating, Ventilation and Air-conditioning) system parameters. Utility rates are critical for energy cost calculations. Based on information in Section 6, actual utility rates have been used for the S.T. Dana Building.

7.1.1 Energy Simulation Results

The following tables provide a summary of the energy use and cost of the LEED™ Base Case and Proposed Case Building Models. Aggregate energy is composed of energy consumed by regulated and non-regulated systems. Regulated energy systems include HVAC (heating, cooling, fans and pumps), service hot water and interior lighting. Non-regulated systems include plug loads, exterior lighting, garage ventilation and elevators (vertical transportation). Innovation credits can be earned by minimizing energy consumption of non-regulated systems. Energy savings for only regulated systems are considered for LEED™ Energy & Atmosphere credits. Table 12 shows the aggregate energy consumption for the Base Case Model and Table 13 shows the Aggregate energy separated into energy consumed regulated and non- regulated systems because we are concerned only with regulated systems' energy use in this analysis.

Table 12: Aggregate Energy and Cost figures for the Base Case Model

Base Case: Aggregate Energy Demand from eQUEST™			
Utility	Energy	Cost/Unit ($)	Cost
Electricity	1,131,005 kWh	0.082/kWh	$92,742
Chilled Water	2,094 MBtu	19.58/Mbtu	$41,001
Steam	8,267 MBtu	9.77/Mbtu	$80,769
Total			$214,512

Table 13: Regulated and Unregulated Energy Demand for the Base Case Model

Base Case: Regulated & Unregulated Energy Demand from eQUEST™				
	Regulated Energy Demand		**Unregulated Energy Demand**	
Utility	Energy	Cost	Energy	Cost
Electricity	815,506 kWh	$ 66,871	315,498 kWh	$ 25,871
Chilled Water	1,800 MBtu	$ 35,236	294 MBtu	$ 5,764
Steam	6,531 MBtu	$ 63,811	1,736 MBtu	$ 16,957
Total		$ 165,919		$48,592

Table 14 shows the Aggregate Energy and Cost figures for the Proposed Model and Table 15 shows the aggregate energy split into regulated and non-regulated energy use.

Table 14: Aggregate Energy and Cost figures for the Proposed Model

Proposed Case: Aggregate Energy Demand from eQUEST™					
Utility	Energy	Cost/Unit ($)	Cost	% Energy change over Base Case	% Cost change over Base Case
Electricity	851,902 kWh	0.082/kWh	$69,856	-25	-25
Chilled Water	1,518 MBtu	19.58/Mbtu	$29,722	-28	-28
Steam	8,439 MBtu	9.77/Mbtu	$82,449	2	+2
Total			$182,027		-15

Table 15: Regulated & Unregulated Energy Demand for Proposed Model

Proposed Case: Regulated & Unregulated Energy Demand from eQUEST™						
	Regulated Energy Demand			**Unregulated Energy Demand**		
Utility	Energy	Cost	% cost change over Base Case	Energy	Cost	% cost change over Base Case
Electricity	536,707 kWh	$ 44,010	-34	315,195 kWh	$ 25,846	0
Chilled Water	1,214 MBtu	$ 23,762	-33	304 MBtu	$ 5,960	3
Steam	6,709 MBtu	$ 65,550	3	1,730 MBtu	$ 16,899	0
Total		$ 133,323	-20		$48,705	0

Table 16: Summary of Simulation Results

Summary of Simulation Results from eQUEST™						
	Base Case: Regulated Energy & Cost		**Proposed Case: Regulated Energy & Cost**		**% Change over Base Case**	
Utility	Energy(MBtu)	Cost ($)	Energy(MBtu)	Cost ($)	Energy	Cost
Electricity	2,783	66,871	1,832	44,010	-34	-34
Chilled Water	1,800	35,236	1,214	23,762	-33	-33
Steam	6,531	63,811	6,709	65,550	+3	+3
Total	11,114	165,919	9,755	$ 133,323	-12	-20

Table 16 compares the energy use and cost for the Base Case model and the Proposed Case Model. The table shows us that the Electricity and Chilled Water costs has gone down significantly by 34% and 33% respectively whereas the steam costs have in fact increased 3%. The high percentage of cost savings for Chilled Water is because of the use of Radiant Panels in the Proposed Model; Radiant Panels require less Chilled Water. Since electricity is also used apart from steam to produce Chilled Water, we see significant savings in the electricity costs. The renovations lead to an annual savings of 278,799 kWh of electricity and 586 Mbtu of chilled water which in turn saved $22,861 and $11,474 for electricity and chilled water respectively at the current utility rates. The steam usage increased slightly and cost an extra $1739. There is a 12% energy savings and a 20% cost reduction in the energy used by the Proposed Model over the Base case model.

The results are also presented in a graphical format below. Figure 39 shows the annual energy demand by type for the Base Case and the Proposed Case Model. Figure 40 shows the total energy demand for the Base Case and the Proposed Case Model. Figure 41 shows the energy cost by type and Figure 42 shows the total energy cost for the Base Case and the Proposed Case Models.

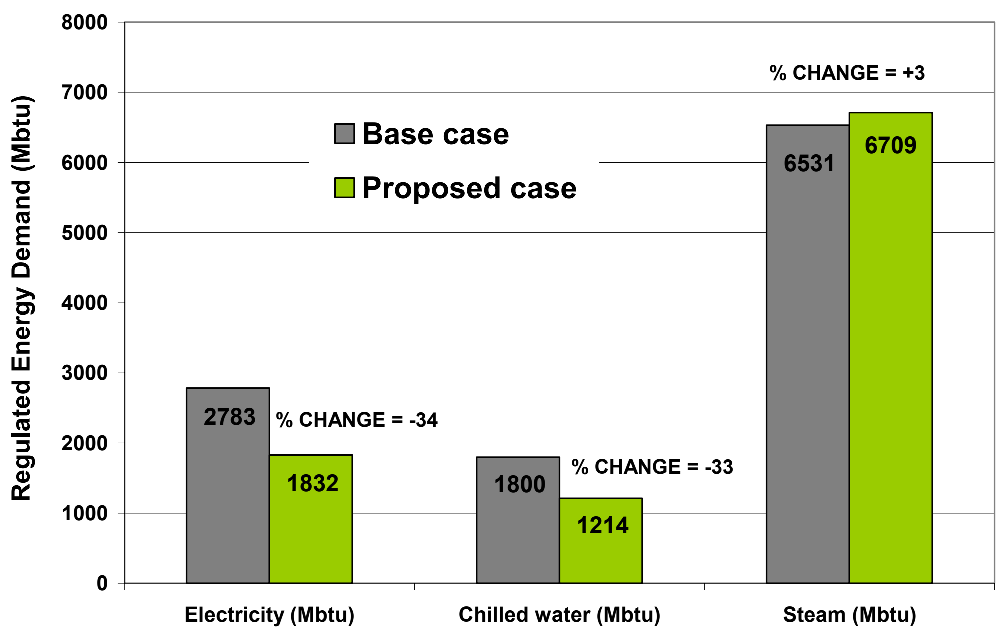


Figure 39: Annual Energy Demand by Type

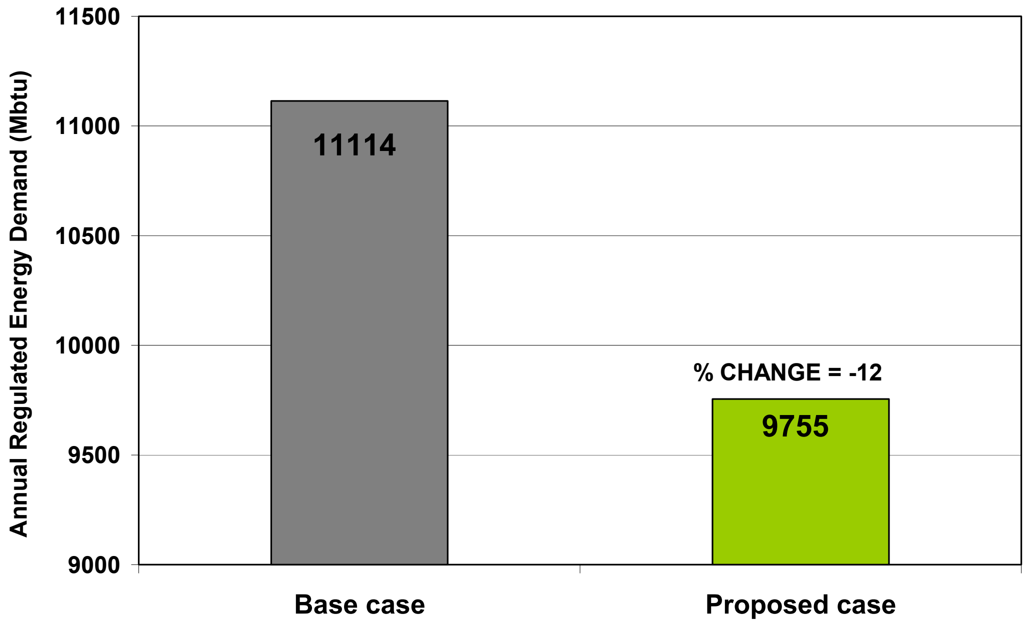


Figure 40: Annual Energy Demand

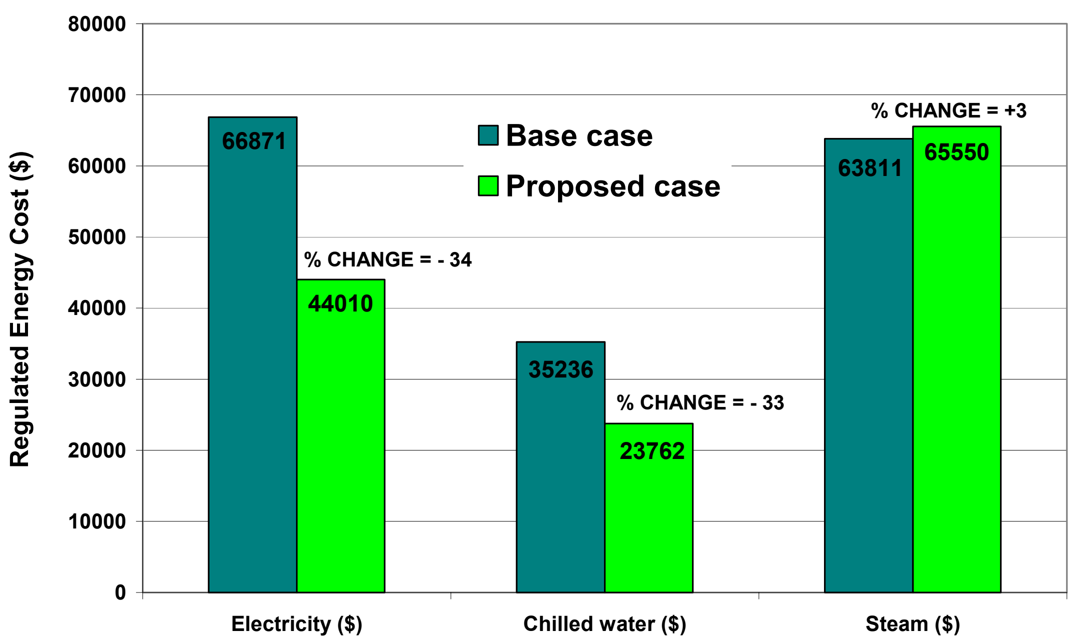


Figure 41: Energy Cost by Type

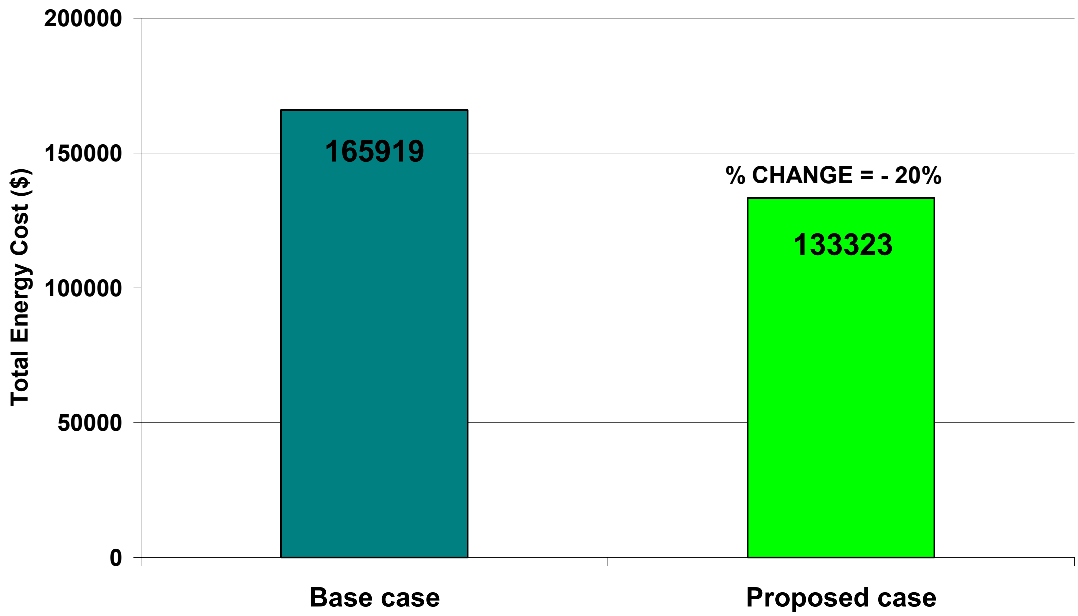


Figure 42: Total Energy Cost

Based upon Amendment #LEED 2.0-E Ac1-133, we can use Table 8c (copied below) from the LEED Energy & Atmosphere Credit 1: Point Interpolation Tables for ASHRAE 90.1-1999. From Table 17, based upon 20% Energy Cost Savings, the S.T. Dana Building design earns 4 LEED points.

Table 17: LEED Points for increasing percentage of cost savings

Existing Buildings ASHRAE 90.1 Scale (Energy Savings)	LEED Points
5%	1
10%	2
15%	3
20%	4
25%	5
30%	6
35%	7
40%	8
45%	9
50%	10

7.1.2 Comparison of Model Simulation Results with Dana Energy consumption

The Base Case and the Proposed Case Model simulation results are compared with the actual Dana energy consumption in Fiscal Year 2002-03. The aggregate energy consumption in the eQUEST^{TM} model is less than the actual total energy consumption by the Dana Building in the Fiscal Year 2002-03 (Table 18). It should first be emphasized that actual Dana Building's energy consumption does not reflect the performance of the completed renovated building. For example the radiant cooling system was not operational during Fiscal Year 2002-03. Despite this limitation the results were compared as a rough verification of the model with the actual building energy demand. These differences can be further explained by various modeling assumptions.

Several approximations have been made in the eQUEST^{TM} model for building parameter such as lighting requirements. Every light fixture in the Dana Building was not modeled but standard lighting assumptions for a university building that were provided by the simulation program were used. Similar approximations were made for equipment and other inputs. Moreover, the weather data used in the simulation program was a 100 year average for Detroit and the energy demand in the model is compared to the energy demand in one fiscal year, namely 2002-03 and this is not a typical year. Another critical factor that could have contributed to the difference is that during fiscal year 2002-03, the Dana Building was still undergoing renovation and part of its HVAC system was being retrofitted while the rest of the HVAC systems worked overtime to heat and cool the building. Typically a building simulation analysis has an overall accuracy that may be plus or minus 10% of the actual building[26].

Table 18: Comparison of Total Energy Demand (Actual versus Model)

Comparison of Total Site Energy Demand (Actual versus Model)	
Source	Total Site Energy Demand in Mbtu
Total energy demand by Dana Bldg. In Fiscal Year 2002-03	12,910
Aggregate Energy demand(eQUEST™ Base Case)	11,114
Aggregate Energy Demand (eQUEST ™ Proposed Case)	9,755

8 SUMMARY OF ENERGY EFFICIENCY MEASURES & CONCLUSIONS

The following sections summarize the various energy efficiency technologies accounted for between the LEED™ Base Case and LEED™ Proposed Case Model simulations.

8.1 Envelope Measures

The following measures are incorporated into the envelope design.

Shading: The windows in the ground floor are set back by one floor, those on the first and second floor are set back by 9 inches and the windows on the third floor are set back by 6 inches.

Atrium glazing: The Atrium glazing has a shading coefficient of 0.1 providing further energy savings.

8.2 Lighting Measures

Lighting in the base-case and the proposed model has been assumed to be the same and therefore does not contribute to energy savings.

8.3 HVAC Measures

The following measures are incorporated into the HVAC system design.

Radiant Cooling Panels are modeled in the Proposed Case Model as a fan coil unit with infinite fan efficiency to simulate zone cooling without any fan energy use. Since radiation only affects surfaces directly without affecting the air in between, the room temperature has been elevated from 75ºF to 78ºF[27]. Human comfort in these zones is equivalent because the occupant is cooled directly by the panels. Radiant Cooling panels are used in the non-laboratory spaces on the ground floor through third floors.

The Base Case energy model has a standard VAV Reheat system instead of the radiant cooling panels in the zones where radiant cooling is used in the real building design and simulated in the Proposed Case Model.

8.4 Conclusions

Colleges and universities are facing severe budgetary challenges as they strive to operate, update, and replace aging, inefficient buildings. Energy costs and student demand for energy-intensive amenities like air conditioning, high-speed Internet connections, and voice mail are increasing almost at the same pace.

As seen in this project energy efficient building improvements can greatly reduce operating costs. Potential for energy savings can come from improvements in building controls that regulate off-hour lighting, heating, and cooling across the entire campus, efficient lighting, appliances, improved heating, ventilation and air-conditioning systems and daylighting. Most of the energy savings for the Dana Building came from using Radiant Cooling Panels for cooling. The renovations lead to an annual savings of 278,799 kWh of electricity and 586 Mbtu of chilled water which in turn saved $22,861 and $11,474 for electricity and chilled water respectively at the current utility rates. The steam usage increased slightly and cost an extra $1739. This resulted in significant savings of 12% in total regulated energy consumption and a 20% dollar cost reduction. Utility rates played a critical role in the energy analysis. The LEED™ cost analysis was very sensitive to utility rates.

A high-performance campus building such as the renovated Dana Building also serves as a teaching tool for environmental education or other similar programs, providing students with hands-on learning opportunities about energy and environmental issues. Students can monitor energy technologies in use, conduct campus building energy audits, or even assist local businesses with energy audits, helping to increase awareness of the potential for energy savings.

8.5 Future Research

Simulation boundaries of the project were limited to the site energy consumption for the Dana Building. Future research can extend the model to include the Central Plant and study the primary energy sources of steam, electricity and Chilled Water. Since most of the savings came from a reduction in the Chilled Water consumption, the primary energy savings for Chilled Water production are expected to be significant. Pollution caused in converting the primary energy sources to steam, electricity and Chilled Water will also be another important research topic.

As mentioned in this report, a building simulation analysis can have an accuracy of plus or minus 10%. As long as there is sufficient consistency in the simulation method, an accurate analysis of the difference between the Base Case and the Proposed Case Model is still possible. A recommendation of this study is that further research on modeling uncertainties relating to the LEED™ credits in the Energy & Atmosphere category be conducted.

9 REFERENCES

[1] Article in the Union of Concerned Scientists' website titled 'Whole Buildings: An Integrating R&D and Policy framework for the 21st century; web address: http://www.ucsusa.org/clean_energy/archive/page.cfm?pageID=113

[2] Citherlet, S.Clarke, J.A., Hand, J., *Integration in building physics simulation.* Energy and Buildings, 2001. 33: p. 451-461.

[3] Jonsson, A., *Tools and methods for environmental assessment of building products – methodological analysis of six selected approaches.* Building and Environment, 2000. 35(3): p.223-238.

[4] Cole, R.J. and N. Larson, *Green building challenge '98, in ASHRAE Journal,* 1998. p.20.

[5] Cole, R., *Emerging trends in building environmental assessment methods.* Building Research and Information, 1998. 26(1): p.3-16

[6] USGBC, *LEED Reference Guide Version 2.0.* 2001, Washington DC: U.S. Green Building Council. 280.

[7] USGBC. *USGBC and the LEED Green Building rating System.* in *Advanced LEED Training Workshop.* 2002. Dearborn, MI: U.S. Green Building Council.

[8] Lovins, Amory, *Energy efficient buildings: institutional barriers and opportunities*. E-Source Strategic Issues Paper, Boulder, CO, 1992.

[9] Hartkopf, Volker, personal Communications. Center for Building Performance and Diagnostics, Carnegie Mellon University, Pittsburgh, PA, January 1995.

[10] Mendell, M. and Smith, A. H., *Consistent pattern of elevated symptoms in air-conditioned buildings: a reanalysis of epidemiologic studies.* Am. J. Public Health, (80) (10) 1990.

[11] Energy Design Resources, Design Brief, *Building Simulation*

[12] Chapman K S., DeGreef J M., Watson R D., 1997, Thermal comfort analysis using BCAP for retrofitting a radiantly heated residence, *ASHRAE Tran*., 1997, vol.103, part 1, paper number PH-97-14-13 (RP-907).

[13] Strand R K., Pederson C O., 1997, Implementation of a radiant heating and cooling model into an integrated building energy analysis program, *ASHRAE Trans*. 1997, vol. 103, Part 1, paper number PH-97-14-2.

[14] Communication with Eric Albert, Manager, Plant Mechanical Engineering, Utilities & Plant Engineering, University of Michigan.

[15] Communication with Bill Verge, Director, Utilities & Plant Engineering, University of Michigan.

[16] Usibelli, Anthony, Greenberg, S. Meal, M., Mitchell, A., Johnson, A., Sweitzer, G., Rubinstein, F., Arasteh, D., *Commercial-sector conservation technologies.* Rep. LBNL-18453, 1985.

[17] Feustel, E. Helmut, *Economizer rating.* Final Rep. prepared for Southern California Edison Company, 1989.

[18] Jump, David and Modera, M., *Energy impacts of attic duct retrofits in Sacramento houses.* Proc. ACEEE 1994 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, DC.

[19] Online source, *ToolBase Services – The Home Building Industry's Technical Information Resource*, http://www.toolbase.org/tertiaryT.asp?DocumentID=2097&CategoryID=1435

[20] CBS Newsletter, *Hydronic Radiant Cooling Systems,* Fall 1994, p.4.

[21] Energy Design Resources, Design Brief, *Radiant Cooling, http://www.energydesignresources.com/publications/design_briefs/dbv2_radiantcooling.html*

[22] Stetiu, Corina, *"Energy and Peak Power Savings potential of Radiant Cooling Systems in U.S. Commercial buildings",* Energy and Buildings, v. 30, no. 2 (1999).

[23] Timmons, Sean., Senior Mechanical Engineer, Arup and Partners, 901 Market Street, Suite 260, San Francisco, CA 94103, email sean.timmons@arup.com

[24] Sodec, Franc, *"Economic Viability of Cooling Ceiling Systems",* Energy and Buildings, v. 30, no. 2 (1999)

[25] McDonell, Geoff., P.E., *Radiant Cooling and Greenhouse Gases,* PM Engineer, Issue June 2001.

[26] Online source, Nall, Daniel H., AIA, P.E. Director of Advanced Technology, Flack + Kurtz Inc. New York, http://www.flackandkurtz.com/

[27] Communication with Daly, Alan P. E. Taylor Engineering, CA

APPENDICES

APPENDIX A: LEED Version 2.1 Registered Project Checklist

Version 2.1 Registered Project Checklist

Project Name
City, State

Yes	?	No			
			Sustainable Sites		**14 Points**
Y			Prereq 1	**Erosion & Sedimentation Control**	Required
			Credit 1	**Site Selection**	1
			Credit 2	**Urban Redevelopment**	1
			Credit 3	**Brownfield Redevelopment**	1
			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
			Credit 4.4	**Alternative Transportation**, Parking Capacity and Carpooling	1
			Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
			Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
			Credit 6.1	**Stormwater Management**, Rate and Quantity	1
			Credit 6.2	**Stormwater Management**, Treatment	1
			Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
			Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
			Credit 8	**Light Pollution Reduction**	1

Yes	?	No			
			Water Efficiency		**5 Points**
			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
			Credit 2	**Innovative Wastewater Technologies**	1
			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Yes ? No

Yes	?	No		Energy & Atmosphere	17 Points
Y			Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
			Credit 1	**Optimize Energy Performance**	1 to 10
			Credit 2.1	**Renewable Energy**, 5%	1
			Credit 2.2	**Renewable Energy**, 10%	1
			Credit 2.3	**Renewable Energy**, 20%	1
			Credit 3	**Additional Commissioning**	1
			Credit 4	**Ozone Depletion**	1
			Credit 5	**Measurement & Verification**	1
			Credit 6	**Green Power**	1

Yes	?	No		Materials & Resources	13 Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
			Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
			Credit 1.2	**Building Reuse**, Maintain 100% of Shell	1
			Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
			Credit 2.1	**Construction Waste Management**, Divert 50%	1
			Credit 2.2	**Construction Waste Management**, Divert 75%	1
			Credit 3.1	**Resource Reuse**, Specify 5%	1
			Credit 3.2	**Resource Reuse**, Specify 10%	1
			Credit 4.1	**Recycled Content**, Specify 5% (post-consumer + ½ post-industrial)	1
			Credit 4.2	**Recycled Content**, Specify 10% (post-consumer + ½ post-industrial)	1
			Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
			Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
			Credit 6	**Rapidly Renewable Materials**	1
			Credit 7	**Certified Wood**	1

Yes	?	No	Indoor Environmental Quality	15 Points

Yes	?	No	Credit		Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
			Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	1
			Credit 2	**Ventilation Effectiveness**	1
			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
			Credit 4.2	**Low-Emitting Materials**, Paints	1
			Credit 4.3	**Low-Emitting Materials**, Carpet	1
			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
			Credit 6.1	**Controllability of Systems**, Perimeter	1
			Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
			Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
			Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Yes	?	No	Innovation & Design Process	**5** Points

Yes	?	No	Credit		Points
			Credit 1.1	**Innovation in Design**: Provide Specific Title	1
			Credit 1.2	**Innovation in Design**: Provide Specific Title	1
			Credit 1.3	**Innovation in Design**: Provide Specific Title	1
			Credit 1.4	**Innovation in Design**: Provide Specific Title	1
			Credit 2	**LEED™ Accredited Professional**	1

Yes	?	No	**Project Totals (pre-certification estimates)**	**69** Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

APPENDIX B: Fee Summary for LEED Certification

Fee Summary*			
	Less than 75,000 Square Feet	**75,000 - 300,000 Square Feet**	**More than 300,000 Square Feet**
Charges	Fixed Rate	Based on Square Ft.	Fixed Rate
Registration			
Members	$750.00	$0.01 per Square Foot	$3,000.00
Non-Members	$950.00	$0.0125 per Square Foot	$3,750.00
Certification			
Members	$1,500.00	$0.02 per Square Foot	$6,000.00
Non-Members	$1,875.00	$0.025 per Square Foot	$7,500.00
All fees are subject to change.			
*Certification fee for projects registered under Version 2.0 (prior to November 15, 2002) is $1200 (members) or $1500 (non-members).			

APPENDIX C: Dana building: LEED™ Scorecard as of 3/19/2003

Dana Building (LEED #0326) — LEED™ Scorecard of 3/19/2003

Y	?	N	Total Project Score	Possible Points
41	7	21	**Total Project Score**	69

Certified 26 to 32 points Silver 33 to 38 points Gold 39 to 51 points Platinum 52 or more points

Y	?	N		Sustainable Sites	Possible Points 14
7		7			
Y			Prereq 1	**Erosion & Sedimentation Control**	
1			Credit 1	**Site Selection**	1
1			Credit 2	**Urban Redevelopment**	1
		1	Credit 3	**Brownfield Redevelopment**	1
1			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
		1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
		1	Credit 4.3	**Alternative Transportation**, Alternative Fuel Refueling Stations	1
1			Credit 4.4	**Alternative Transportation**, Parking Capacity	1
1			Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
		1	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
		1	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
		1	Credit 6.2	**Stormwater Management**, Treatment	1
1			Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands** Non-Roof	1
		1	Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands** Roof	1
1			Credit 8	**Light Pollution Reduction**	1

Y	?	N		Water Efficiency	Possible Points 5
5					
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
1			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
1			Credit 2	**Innovative Wastewater Technologies**	1
1			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
1			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Y	?	N		Energy & Atmosphere	Possible Points 17
7	2	8			
Y			Prereq 1	**Fundamental Building Systems Commissioning**	
Y			Prereq 2	**Minimum Energy Performance**	
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	
2			Credit 1.1	**Optimize Energy Performance**, 20% New / 10% Existing	2
2			Credit 1.2	**Optimize Energy Performance**, 30% New / 20% Existing	2
	2		Credit 1.3	**Optimize Energy Performance**, 40% New / 30% Existing	2
		2	Credit 1.4	**Optimize Energy Performance**, 50% New / 40% Existing	2
		2	Credit 1.5	**Optimize Energy Performance**, 60% New / 50% Existing	2
		1	Credit 2.1	**Renewable Energy**, 5%	1
		1	Credit 2.2	**Renewable Energy**, 10%	1
		1	Credit 2.3	**Renewable Energy**, 20%	1
1			Credit 3	**Additional Commissioning**	1
1			Credit 4	**Ozone Depletion**	1
1			Credit 5	**Measurement & Verification**	1
		1	Credit 6	**Green Power**	1

Y	?	N		Materials & Resources	Possible Points 13
9		4			
Y			Prereq 1	**Storage & Collection of Recyclables**	
1			Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
1			Credit 1.2	**Building Reuse**, Maintain 100% of Existing Shell	1
1			Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
		1	Credit 2.1	**Construction Waste Management**, Divert 50%	1
		1	Credit 2.2	**Construction Waste Management**, Divert 75%	1
		1	Credit 3.1	**Resource Reuse**, Specify 5%	1
		1	Credit 3.2	**Resource Reuse**, Specify 10%	1
1			Credit 4.1	**Recycled Content**, Specify 25%	1
1			Credit 4.2	**Recycled Content**, Specify 50%	1
1			Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
1			Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
1			Credit 6	**Rapidly Renewable Materials**	1
1			Credit 7	**Certified Wood**	1

Y	?	N		Indoor Environmental Quality	Possible Points 15
10	3	2			
Y			Prereq 1	**Minimum IAQ Performance**	
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	
1			Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	1
1			Credit 2	**Increase Ventilation Effectiveness**	1
	1		Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
	1		Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
1			Credit 4.2	**Low-Emitting Materials**, Paints	1
1			Credit 4.3	**Low-Emitting Materials**, Carpet	1
	1		Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
1			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
1			Credit 6.1	**Controllability of Systems**, Perimeter	1
		1	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
1			Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
1			Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
1			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
		1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Y	?	N		Innovation & Design Process	Possible Points 5
3	2				
1			Credit 1.1	**Innovation in Design**: Chilled Ceiling Panels	1
1			Credit 1.2	**Innovation in Design**: Occupant Handbook / Education	1
	1		Credit 1.3	**Innovation in Design**: PV Array / Daylight Control	1
	1		Credit 1.4	**Innovation in Design**: Preserving Cultural Heritage	1
1			Credit 2	**LEED™ Accredited Professional**	1

U S Green Building Council — **Scorecard** — LEED™ Calculator 2.0

APPENDIX D: Comparative List of Available Simulation Software

Program name	Comments	Price	For further information
Simple analysis programs			
eQUEST	Microsoft Windows-based graphical user interface (GUI), based on the DOE-2.2 calculation engine. Lots of templates for a range of building types.	Free.	Download a copy of the program from www.energydesignresources.com or www.doe2.com
Energy-10	Developed jointly by the National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Berkeley Solar Group, Sustainable Building Industries Council, and the U.S. Department of Energy. Intended for performing quick energy simulations. Program comes with "Designing Low-Energy Buildings" manual.	$250 for professionals and $50 for full-time students or professors.	Sustainable Building Industries Council (formerly the Passive Solar Industries Council) 1511 K Street NW, Suite 600 Washington, DC 20005 tel 202-628-7400 ext 210 fax 202-393-5043 e-mail psicouncil@aol.com web www.psic.org
Detailed analysis programs			
DOE-2	A well-validated program that has been in existence since 1978. There is no user interface to speak of; program inputs are made with a standard text-editing program. Extensive documentation of program inputs is available in printed form. Though there are many variants available with slightly different interfaces, most of these are based on the J.J. Hirsch version of DOE-2.1E.	Download for free or buy a CD containing all DOE-2 versions for $65.	James J. Hirsch & Associates 12185 Presilla Road Camarillo, CA 93012-9243 tel 805-532-1045 fax 805-532-2401 Download a license agreement from www.doe2.com
VisualDOE 2.6	A Microsoft Windows-based graphical user interface for DOE-2.1E that can greatly reduce input time. Has an extensive library of predefined schedules, construction assemblies, and glass types. Has the ability to import an AutoCAD *.dxf file for developing zone inputs. Version 3.0, which is based on DOE-2.2, will be available soon.	$495 for single-user version and $695 for two-user network version. Additional users can be added for $200 each.	Charles Eley Associates Charles Eley or Erik Kolderup 142 Minna Street San Francisco, CA 94105 tel 415-957-1977 fax 415-957-1381 e-mail support@eley.com web www.eley.com
PowerDOE	Feature-rich GUI based on the DOE-2.2 calculation engine. Allows non-rectangular walls and provides nice renderings of the building that you have input.	$278 for a no-expiration license. ($250 is the cash discount price.)	James J. Hirsch & Associates 12185 Presilla Road Camarillo, CA 93012-9243 tel 805-532-1045 fax 805-532-2401 Download a license agreement from www.doe2.com; you can also get a free 90-day evaluation license from the same location.
Special purpose programs			
EnergyPro	Based on DOE-2.1E and used for documenting compliance with Title 24 requirements. It is also good for setting up noncompliance models due to its extensive library of building materials and HVAC equipment.	Cost varies depending on which program modules you purchase. Cost is $895 for user interface and nonresidential DOE-2 module.	Gabel Dodd/EnergySoft LLC Demian Vonderkulen 100 Galli Drive #1 Novato, CA 94949-5657 tel 415-883-5900 fax 415-883-5970 e-mail demian@energysoft.com web www.energysoft.com
Trane Trace 600	HVAC load calculation program that also has many energy analysis capabilities. Provides engineering checks of most program inputs for reasonableness. DOS-based interface. Not an hourly calculation program.	$1,795 for single-user license, $2,693 for a site license. There is also an annual license renewal fee of 23 percent of the program first cost.	The Trane Company/C.D.S. Group 3600 Pammel Creek Road La Crosse, WI 54601-7599 tel 608-787-3926 fax 608-787-3005 e-mail cdshelp@trane.com web www.trane.com
Carrier Hourly Analysis Program (HAP)	An hourly calculation HVAC load calculation program that can also be used for energy analysis. Windows-based interface.	$1,195	Contact your local Carrier representative or www.carrier.com.

Source: Manufacturer's data

APPENDIX E: East University Absorption Chiller (Data for Fiscal 02-03)

Fuel requirements for the production of chilled water
0.48 kWh of electricity is required to produce 1 ton-hr of Chilled Water.
Electricity: 0.48 kWh/ton-hr
After conversion:
0.1365 Btu of electricity is required to produce 1 Btu of Chilled Water.

21 lbs of steam is required to produce 1 ton-hr of Chilled Water.
Steam: 21 lbs/ton-hr
After conversion:
1.75 Btu of steam is required to produce 1 ton-hr of Chilled water.

Therefore 0.1365 Btu of electricity and 1.75 Btu of steam is required to produce 1 Btu of Chilled Water.

Total fuel requirement:
1.8865 Btu of fuel (electricity and steam) is required to produce 1 Btu of Chilled Water.

Unit Conversion Used
1 ton-hr = 12,000 Btu of Chilled Water
1 lb of steam = 1000 Btu
1 kWh = 3412 Btu

APPENDIX F: Base Case Model - eQUEST™ Reports

I. Report – ES-D Energy Cost Summary

```
DOE-B2.2-41j  12/04/2003    16:45:05  BDL RUN  2

REPORT- ES-D Energy Cost Summary
WEATHER FILE- Detroit      MI TMY2
-----------------------------------------------------------------------
                                   METERED      TOTAL  VIRTUAL   RATE
                                   ENERGY       CHARGE RATE      USED ALL
UTILITY-RATE RESOURCE      METERS  UNITS/YR      ($)   ($/UNIT)  YEAR?
-----------------------------------------------------------------------

Elec Rate    ELECTRICITY   EM2 EM1 1131005.KWH  92742 0.082     YES
CHW Rate     CHILLED-WATER CM1     2094. MBTU   41001 19.58     YES
Steam Rate   STEAM         SM1     8267. MBTU   80769 9.77      YES
-----------------------------------------------------------------------
                                                214512
```

II. Report – BEPU Building Utility Performance

```
DOE-B2.2-41j  12/04/2003    16:45:05  BDL RUN  2

REPORT- BEPU Building Utility Performance
WEATHER FILE- Detroit      MI TMY2
---------------------------------------------------------------------------------------------------------------------------------

                           TASK      MISC     SPACE     SPACE      HEAT     PUMPS      VENT    REFRIG  HT PUMP   DOMEST       EXT
                 LIGHTS   LIGHTS    EQUIP   HEATING   COOLING    REJECT     & AUX      FANS   DISPLAY  SUPPLEM  HOT WTR     USAGE     TOTAL
                -------  -------  -------   -------   -------   -------   -------   -------   -------  -------  -------   -------  --------
EM2
ELECTRICITY
KWH              43323.       0.  208115.        0.        0.        0.        0.    64060.        0.       0.       0.        0.   315498.

EM1
ELECTRICITY
KWH             357995.       0.       0.        0.        0.        0.    39140.   418371.        0.       0.       0.        0.   815506.

FM1
NATURAL-GAS
THERM                0.       0.       0.        0.        0.        0.        0.        0.        0.       0.       0.        0.        0.

SM1
STEAM
MBTU                 0.       0.       0.     8267.        0.        0.        0.        0.        0.       0.       0.        0.     8267.

CM1
CHILLED-WATER
MBTU                 0.       0.       0.        0.     2094.        0.        0.        0.        0.       0.       0.        0.     2094.


           TOTAL ELECTRICITY   1131005. KWH       10.538 KWH     /SQFT-YR GROSS-AREA   10.538 KWH     /SQFT-YR NET-AREA
           TOTAL STEAM            8267. MBTU       0.077 MBTU    /SQFT-YR GROSS-AREA    0.077 MBTU    /SQFT-YR NET-AREA
           TOTAL CHILLED-WATE     2094. MBTU       0.020 MBTU    /SQFT-YR GROSS-AREA    0.020 MBTU    /SQFT-YR NET-AREA

           PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE =  2.9
           PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED                =  0.0

           NOTE:  ENERGY IS APPORTIONED HOURLY TO ALL END-USE CATEGORIES.
```

III. Hourly Report – Lab System Report

DOE-B2.2-41j 12/04/2003   16:45:05 BDL RUN 2

HOURLY REPORT- Lab System Report
WEATHER FILE- Detroit   MI TMY2PAGE365 - 1

	Gd Floor VAV TOT HTG COIL PWR BTU/HR	Gd Floor VAV TOT CLG COIL PWR BTU/HR	Gd Floor VAV TOT ZONE HTG PWR BTU/HR	Gd Floor VAV TOT ZONE CLG PWR BTU/HR
	----(5)	----(6)	----(7)	----(8)
1231 1	-184473.	0.	-100716.	0.
1231 2	-196381.	0.	-100917.	0.
1231 3	-207741.	0.	-102210.	0.
1231 4	-178006.	0.	-101921.	0.
1231 5	-165671.	0.	-101384.	0.
1231 6	-159856.	0.	-101140.	0.
1231 7	-159873.	0.	-96637.	0.
1231 8	-159853.	0.	-89517.	0.
1231 9	-313414.	0.	-120855.	0.
123110	-575888.	0.	-145890.	0.
123111	-186238.	0.	-14675.	0.
123112	-173339.	0.	-14015.	0.
123113	-158751.	0.	-8827.	0.
123114	-158849.	0.	-13376.	0.
123115	-472522.	0.	-12868.	0.
123116	-231227.	0.	-51072.	0.
123117	-219800.	0.	-57987.	0.
123118	-337816.	0.	-114500.	0.
123119	-366868.	0.	-134533.	0.
123120	-365529.	0.	-134316.	0.
123121	-339053.	0.	-132588.	0.
123122	-235930.	0.	-90221.	0.
123123	-117770.	0.	-51175.	0.
123124	-225597.	0.	-117634.	0.
DAILY SUMMARY (DEC 31)				
MN	-575888.	0.	-145890.	0.
MX	-117770.	0.	-8827.	0.
SM	-5890444.	0.	-2008978.	0.
AV	-245435.	0.	-83707.	0.
MONTHLY SUMMARY (DEC)				
MN	-1047382.	0.	-264835.	0.
MX	-43115.	0.	0.	0.
SM	-205750864.	0.	-69344576.	0.
AV	-276547.	0.	-93205.	0.
YEARLY SUMMARY				
MN	-1255621.	0.	-417656.	0.
MX	0.	1113568.	0.	0.
SM	-1146331776.	294399648.	-589309184.	0.
AV	-130860.	33607.	-67273.	0.

APPENDIX G: Proposed Case Model - eQUEST^{TM} Reports

I. Report – ES-D Energy Cost Summary

REPORT- ES-D Energy Cost Summary
WEATHER FILE- Detroit MI TMY2

UTILITY-RATE	RESOURCE	METERS	METERED ENERGY UNITS/YR	TOTAL CHARGE ($)	VIRTUAL RATE ($/UNIT)	RATE USED ALL YEAR?
Elec Rate	**ELECTRICITY**	**EM2 EM1**	**851902 KWH**	**69856.**	**0.082**	**YES**
CHW Rate	**CHILLED-WATER**	**CM1**	**1518. MBTU**	**29722.**	**19.58**	**YES**
Steam Rate	**STEAM**	**SM1**	**8439. MBTU**	**82449.**	**9.77**	**YES**
				182027.		

ENERGY COST/GROSS BLDG AREA:1.36
NERGY COST/NET BLDG AREA:1.36

II. Report – BEPU Building Utility Performance

DOE-B2.2-41j 12/04/2003   23:52:02 BDL RUN 1

REPORT- BEPU Building Utility Performance
WEATHER FILE- Detroit   MI TMY2

	LIGHTS	TASK LIGHTS	MISC EQUIP	SPACE HEATING	SPACE COOLING	HEAT REJECT	PUMPS & AUX	VENT FANS	REFRIG DISPLAY	HT PUMP SUPPLEM	DOMEST HOT WTR	EXT USAGE	TOTAL
EM2													

0 ELECTRICITY

	LIGHTS	TASK LIGHTS	MISC EQUIP	SPACE HEATING	SPACE COOLING	HEAT REJECT	PUMPS & AUX	VENT FANS	REFRIG DISPLAY	HT PUMP SUPPLEM	DOMEST HOT WTR	EXT USAGE	TOTAL
KWH	43323.	0.	208115.	0.	0.	0.	0.	63756.	0.	0.	0.	0.	315195.
EM1 ELECTRICITY KWH	357995.	0.	0.	0.	0.	0.	49650.	129062.	0.	0.	0.	0.	536707.
FM1 NATURAL-GAS THERM	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SM1 STEAM MBTU	0.	0.	0.	8439.	0.	0.	0.	0.	0.	0.	0.	0.	8439.
CM1 CHILLED-WATER MBTU	0.	0.	0.	0.	1518.	0.	0.	0.	0.	0.	0.	0.	1518.

TOTAL ELECTRICITY	851902. KWH	7.938 KWH	/SQFT-YR GROSS-AREA	7.938 KWH /SQFT-YR NET-AREA
TOTAL STEAM	8439. MBTU	0.079 MBTU	/SQFT-YR GROSS-AREA	0.079 MBTU /SQFT-YR NET-AREA
TOTAL CHILLED-WATE	1518. MBTU	0.014 MBTU	/SQFT-YR GROSS-AREA	0.014 MBTU /SQFT-YR NET-AREA

PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE = 0.1
PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED   = 0.0

NOTE: ENERGY IS APPORTIONED HOURLY TO ALL END-USE CATEGORIES.

III. Hourly Report – Lab System Report

```
DOE-B2.2-41j  12/04/2003    23:52:02  BDL RUN  1

HOURLY REPORT- Lab System Report
WEATHER FILE- Detroit      MI TMY2PAGE365 -  1
-------------------------------------------------------------------------------
--------------------------------------------------
          Gd Floor      Gd Floor      Gd Floor      Gd Floor
           VAV           VAV           VAV           VAV
          TOT HTG       TOT CLG       TOT ZONE      TOT ZONE
          COIL PWR      COIL PWR      HTG PWR       CLG PWR
          BTU/HR        BTU/HR        BTU/HR        BTU/HR

          ----( 5)      ----( 6)      ----( 7)      ----( 8)
1231 1      -184471.            0.      -100731.            0.
1231 2      -196380.            0.      -100925.            0.
1231 3      -207740.            0.      -102213.            0.
1231 4      -178005.            0.      -101906.            0.
1231 5      -165670.            0.      -101363.            0.
1231 6      -159855.            0.      -101118.            0.
1231 7      -159872.            0.       -96611.            0.
1231 8      -159852.            0.       -89487.            0.
1231 9      -313415.            0.      -120825.            0.
123110      -575888.            0.      -145859.            0.
123111      -186238.            0.       -14666.            0.
123112      -173339.            0.       -14012.            0.
123113      -158751.            0.        -8825.            0.
123114      -158849.            0.       -13374.            0.
123115      -472522.            0.       -12867.            0.
123116      -231227.            0.       -51072.            0.
123117      -219800.            0.       -57995.            0.
123118      -337816.            0.      -114510.            0.
123119      -366868.            0.      -134532.            0.
123120      -365529.            0.      -134304.            0.
123121      -339053.            0.      -132574.            0.
123122      -235931.            0.       -90208.            0.
123123      -117770.            0.       -51275.            0.
123124      -225599.            0.      -117927.            0.

 DAILY SUMMARY (DEC 31)
    MN      -575888.            0.      -145859.            0.
    MX      -117770.            0.        -8825.            0.
    SM     -5890438.            0.     -2009178.            0.
    AV      -245435.            0.       -83716.            0.

 MONTHLY SUMMARY (DEC)
    MN     -1047382.            0.      -264692.            0.
    MX       -43116.            0.            0.            0.
    SM   -205538560.            0.    -69331416.            0.
    AV      -276262.            0.       -93187.            0.

 YEARLY SUMMARY
    MN     -1255621.            0.      -416667.            0.
    MX            0.      1155013.            0.            0.
    SM  -1140685184.    304394656.   -588963776.            0.
    AV      -130215.        34748.       -67233.            0.
```