{ TC "'CHAPTER ONE: INTRODUCTION"' \l 1 }CHAPTER **ONE**

INTRODUCTION

1.1 Overview{ TC "1.1 Overview" \l 2 }

According to the most recent version of the Commercial Buildings Energy Consumption and Expenditures survey (CBECS), the 4.8 million commercial buildings in the United States consume 5.5 quadrillion Btu of electricity, natural gas, fuel oil , and district heat each year. If conversion losses associated with electricity generation are included, the overall energy consumed by commercial buildings increases to about 10.8 quadrillion Btu (EIA, 1992). Because a building's construction has a large impact on its energy use, decisions about the how buildings are constructed in general have a great impact on our nation's energy use. Furthermore, buildings can serve a useful life of 50 to 100 years or more. If one considers the full impact of construction methods over the building's useful life, the decisions affecting the energy requirements of the building have an even greater impact.

The purpose of this thesis is to take a close look at the energy implications of decisions made during a new commercial building's design and construction phases. The particular areas to be examined are in two categories. The first is to find the effect of changes in building envelope construction on the energy use and cost of space conditioning a commercial building. The building envelope will be investigated by finding the energy savings resulting from measures required by new standards for building construction. These measures result primarily from adding insulation to building envelopes. The optimal level of insulation in walls, roof and building perimeter, considering the added labor and material costs, will be calculated. ASHRAE Standard 90.1 - 1989 will be used as a basis for the comparison of different building envelope options.

The second area to be investigated is the energy savings resulting from daylighting measures in new buildings. Daylighting is the use of increased, high efficiency glazing in a building to make use of natural light during the day. Energy savings from daylighting occur both from the direct energy savings from decreased use of electric lighting, and from decreased cooling loads resulting from a lower lighting load. The magnitude of these energy savings based on a simplified daylighting model will be investigated and compared to the energy savings resulting from changes in building standards.

Decisions with great potential for changing the energy use of a building are made during the preliminary conceptual phases of design. The typical way for a commercial building project to proceed is for the architect to design the building and then give the building design to a mechanical engineer. The engineer then designs a heating and cooling system to satisfy the load requirements of the building. The architect thus establishes the building energy requirements and then the mechanical engineer has to design to meet them. From an energy use standpoint, this procedure is far from optimal. Energy use is usually addressed at the end of the design process when it is too late to do anything about many factors having a large contribution to the energy use of the building.

A team design approach, where both engineers and architects are involved from the beginning of the building design process, provides a method for energy issues to be considered throughout the design process. Using a team approach would allow engineers to provide some guidance to designers about the energy use implications of their decisions during the conceptual phases when these decisions are made. The use of daylighting in commercial buildings is an example of a technology where this type of team approach is essential. To make good use of daylighting requires both an architect who understands how windows will affect his or her design and an engineer who can accurately assess the heating and cooling energy use implications of these decisions.

This thesis will help to quantify the energy savings that a team design approach might achieve. By considering only the engineering aspects of envelope and daylighting, an upper bound for the energy savings that one could achieve may be set. However, the magnitude of these savings will offer some indication of the value of pursuing this type of integrated design approach.

1.2 Scope{ TC "1.2 Scope" \l 2 }

This thesis is based on a case study of two commercial buildings. Computer models were developed to estimate the energy use of these buildings, and to assess the effects of changing characteristics of the building designs. Thus for the analysis to be applicable to other buildings, it was important to choose buildings that were typical of current construction methods. The computer models were calibrated using two existing buildings, constructed in Madison, Wisconsin in 1992. They were chosen to be representative of typical new construction in Wisconsin in envelope design.

The two buildings studied were a retail building and an office building. These were chosen for several reasons. The first is that retail and office buildings are the two largest sectors of commercial building stock in the country. In the U.S. retail and office buildings each make up 21% of the commercial building floor space, for a combined total of 42% (EIA, 1992). In Wisconsin, retail and office space combined make up 33% of the total building floor space in the state. A second reason for choosing office and retail buildings is that these buildings are relatively energy intensive. They tend to have high internal loads from lighting and equipment, resulting in large cooling loads. Because most electric utilities have their system peaks coincident with summer cooling loads, any energy savings of these cooling loads have great impact on overall system demand. So a third reason to study commercial buildings is that they have high coincidence with utility peak demands, because they are usually occupied during weekday afternoons.

Energy savings in the commercial sector have typically ranked among the most cost effective energy efficiency measures for demand-side programs to achieve. Fickett et al reported estimates of the cost of achieving energy savings in different end uses and market sectors (Fickett, 1990). They found estimates of the cost of commercial cooling energy savings from one to one and a half cents per kilowatt hour of energy saved (0.01 to 0.015 $/kWh). They found estimates of lighting energy savings ranging from negative values (i.e. more efficient lighting had a lower net first cost) to one and a half cents per kilowatt hour saved. Thus achieving energy savings in these sectors should be given a high priority because the cost of achieving the savings are lower than the costs of many energy supply sources.

The scope of the analysis will be limited to the building envelope and daylighting strategies. Although equipment models were created to estimate the energy use of the buildings, these were used only to assess the relative benefit of changes to the envelope. Energy savings resulting from building energy standards were thus limited to the envelope and lighting portions of the standards.

Existing commercial buildings were used as a basis for the analysis rather than prototype buildings. Several studies have used prototype buildings to determine the energy use impacts of buildings. Schliesing et al used a prototype building to represent both office and retail buildings together in one model (Schliesing et al, 1995). Prototype buildings were also used to develop ASHRAE Standard 90.1-1989.

Existing buildings were used, rather than prototype buildings, for several reasons. First, prototype buildings are simply not real. They are artificial constructs designed to offer some representation of an entire class of building stock, rather than a real building. Studies of prototype buildings may be biased by what the authors believe to be standard building practice, or typical construction. A second reason for using existing buildings is that the building models can be validated with field data. Both of the buildings in this study had two full years of billing data with which to verify the models. The building models thus had two “reality checks” in that they represented real building construction and that the energy use was calibrated to historical energy use. A third reason for basing the models on real buildings is that it allows the analysis to assess how the new building standards compare to current practice in the construction industry. For example, the industry practice may be ahead of building standards in some areas. If new energy standards require insulation levels that are already nearly standard practice, they have no real impact. By comparing the building characteristics required by standards to recently constructed buildings, it insures that the proper baseline is used for assessing the energy impacts of those standards.

The use of existing buildings does, however, limit the generalization of results from the analysis. The savings found for applying energy saving measures to these buildings should not be extrapolated to other specific buildings, unless they are very similar in construction and climate to those studied here. Nor should the savings found here be used as a proxy for those possible in the entire office or retail sectors of commercial buildings. The intent of the analysis presented here is only to show the level of energy savings that could reasonably be expected from real buildings under a number of different scenarios.

1.3 The Energy Policy Act of 1992{ TC "1.3 The Energy Policy Act of 1992" \l 2 }

The Energy Policy Act of 1992 (EPACT) is a broad-reaching law enacted to promote the efficient use of energy in the United States. The act sets new requirements in many different areas including energy efficient investments by utilities, equipment and appliance efficiency standards, and the energy management of state and federally owned buildings. It also has provisions regulating natural gas imports, alternative fuels, electric motor vehicles, coal research, nuclear power plant licensing, and a host of other energy-related issues.

The portion of EPACT of interest here is that dealing with energy-efficiency standards in new buildings. The act requires that all states enact building codes for commercial buildings that are at least as stringent as ASHRAE Standard 90.1 - 1989.

> Section 304 (b) of EPACT requires every one of the 50 states to certify to the Secretary of the U.S. Department of Energy (DOE) as to the review and updating of the provisions of their commercial building codes regarding energy efficiency. This certification shall include a demonstration that the state's code provisions meet or exceed the requirements of ASHRAE/IES Standard 90.1 - 1989. Certifications were due to the Secretary on October 24, 1994, two years after the date of EPACT enactment (Schliesing et al, 1995).

Thus, each state should by now have enacted a standard either equivalent to, or more stringent than, ASHRAE Standard 90.1. Those states wishing to write their own energy codes, rather than adopt the ASHRAE standard, are responsible for demonstrating that their codes are as stringent.

The thesis evaluates the energy use implications of design changes that might result from meeting ASHRAE Standard 90.1 - 1989. This standard is used as a basis here because it is used as a basis for evaluating all of the commercial building codes in the U.S.

So far, only a fraction of the states in the U.S. have complied with EPACT by enacting commercial building codes. In a study for Pacific Northwest Laboratory, Schliesing et al found that only 14 states had developed building codes that strictly met the requirements of the act in terms of both scope and technical comparisons. Another 5 states marginally met the criteria of EPACT. The remaining 31 states currently had building codes that failed to meet the requirements in some fashion, with 14 states failing in both scope and technical comparisons.

Wisconsin's energy code is currently undergoing revision to meet the requirements of EPACT. The state has adopted a revised version of the Industrial Labor and Human Relations (ILHR) Code 50-64 and 72 relating to energy conservation and heating, ventilating and air conditioning (State of Wisconsin, 1995). State officials believe that these new rules will become effective in Wisconsin in April of 1996 (Mattson, 1995). The rules are largely an adoption of ASHRAE Standard 90.1, with some revisions. The state is also currently working towards obtaining certification from the federal government that the new energy code complies with EPACT.

EPACT is a significant step forward for building codes in the U.S. because it is the first nation-wide, performance-based energy code for commercial buildings. Never before has such a comprehensive standard for building performance in the U.S. been enacted. The energy savings potential of the legislation is vast, given the scope of buildings over which it will be applied. It is also the first performance-based code to have such wide use in the U.S. The standard may be met by prescriptive measures, such as choosing a wall insulation that matches one specified in a table. However, it can also be met by showing that the overall building construction meets a performance criteria. The performance-based option offers greater flexibility to building designers because they can meet the code using any of a large number of combinations of building materials and designs. The method allows much greater flexibility in the application of the code, although it requires a somewhat greater amount of work on the part of the designer to show that compliance will be met. The only previous performance-based code to gain such wide acceptance is California's Title 24 energy code for commercial and residential buildings.

The enactment of the ASHRAE standard may significantly alter the way that buildings are constructed in the U.S. A study of construction practice in Wisconsin has shown that many recently constructed commercial buildings do not meet the requirements of ASHRAE Standard 90.1 (WCDSR, 1994). The study found that 40% of office buildings and nearly 80% of retail buildings had insufficient roof insulation to pass the standard. Thus the enforcement of the standard would have an immediate effect on the way that a large fraction of the buildings in the state are constructed.

1.4 Development of ASHRAE Standard 90.1 - 1989{ TC "1.4 Development of ASHRAE Standard 90.1 - 1989" \l 2 }

ASHRAE Standard 90.1 1989 was developed based on computer simulations of commercial buildings. DOE-2 models were used to develop linear regression models to represent heating and cooling loads in commercial buildings. These regression models were then used to set the performance criteria for the standard.

The building envelope portion of the ASHRAE standard can be met using two general methods. The first of these uses performance-based criteria. Using this method, any building construction that has its total annual projected energy use below a defined level passes the standard. The energy-use criteria depend on the climate where the building is constructed, and the comparison is done on a unit-area basis. The performance-based method thus offers the greatest flexibility to building designers. Trade-offs among the energy use of different components can be made to suit the particular design requirements of the building. For example, a higher performance wall could be added to make-up for energy losses due to lower performance windows. This allows the designers the ability to find the best balance of building materials for the application.

The recommended method for showing compliance with the performance-based standard is by using the ENVSTD computer program. The program uses the same regression equations that were used to develop the standard to estimate the annual heating and cooling loads. These regression equations are shown in the original ASHRAE standard, but using the computer program is much easier than using the equations by hand. To use it the designer calculates a number of basic parameters of the building such as wall R values, window and wall areas, heating capacities, and internal load densities. After typing these parameters into the program, an estimated energy use for the building is calculated to determine whether the building passes or fails.

The commercial building energy-use regression equations were also used to develop a prescriptive standard. To meet the prescriptive standard requires that the designer calculate the same sort of building parameters as for the performance-based standard. The designer then uses tables printed in the standard to look up limiting values for building components. For example, one might find that for given building components, the maximum percentage of fenestration in the building would be limited to 40%. The designer then has the option of either staying below this limit or modifying the window or wall components so that the building falls into another category. Thus the prescriptive standard also has some flexibility, but the allowable trade-offs are more limited in scope than those in the performance standard.

The prescriptive standard was designed to be more stringent than the performance standard. It is possible to design a building that does not pass the prescriptive criteria but does pass the performance standard. This was the case for the two buildings considered in this study. Each passed the performance standard as they were constructed, but neither met the prescriptive criteria. However, it is likely that many, if not most designers, will use the prescriptive criteria to show code compliance. It is somewhat simpler to use, requiring no computer analysis. It is also more deterministic. If the building fails to meet the criteria, one knows exactly what options will bring the building into compliance. For this reason, the application of the prescriptive standard is the principal focus of this thesis.

Both the prescriptive and performance-based ASHRAE standards set out specific methods for determining the U-value, or overall thermal transmittance, of building envelope components. In particular the method calls for correcting the calculation of thermal transmittance for heat transfer through parallel paths within building components. The method thus can account for thermal bridging through components such as metal studs in walls. The addition of this correction is significant because compliance to building codes is often shown using very simple R-value calculations that do not take thermal bridging effects into account. Correcting for thermal bridging effects alone can make a significant change in the standards to which commercial buildings are held.

1.5 Surpassing Codes with Daylighting{ TC "1.5 Surpassing Codes with Daylighting" \l 2 }

One purpose of this paper is to compare the energy savings from improved building standards to the energy savings possible by using daylighting design in commercial buildings.

Good daylighting design is accomplished by maximizing the amount of useful natural light in a space, while minimizing adverse effects of added glazing on heating and cooling loads. Useful natural light is that which can be directed or bounced to areas where it is needed, with minimal glare or contrast. Direct sunlight is not useful to daylight a building. It only adds heat to the building's cooling load and produces "hot spots", or areas that are much brighter than the surroundings. High contrasts areas such as this produce glare and are visually uncomfortable environments for working.

There are many benefits of using daylight in commercial buildings. The first is the direct energy savings resulting from decreased use of electric lights in the buildings. Lighting can account for 40 to 60% of the total energy costs in a commercial building, particularly in office and retail buildings (Aitken, 1995). Electricity is a relatively expensive commodity, compared to other energy sources, so these energy savings have a high economic benefit. Heat generated from electric lighting also contributes to cooling loads, so lighting energy savings have a secondary benefit of decreasing cooling loads in summer. While it is true that there is a heating "penalty" to lighting energy savings (added heat must be supplied in winter to make up for decreased lighting) economic considerations usually make decreased cooling loads more beneficial. Heating energy is usually cheaper, relying on natural gas or other fossil fuels, while cooling energy is usually from the higher priced electricity.

Another benefit from daylighting energy savings is that the greatest energy savings are coincident with utility peak demands. Most electric utilities experience their peak loads during hot summer afternoons when cooling loads are the highest. This is also the time at which the savings from daylighting measures are the greatest. At these times the sun is shining, and any areas lit naturally will be bright enough to turn the lights off. This peak coincidence is particularly true for office and retail buildings that are typically occupied during the peak load hours. At peak hours the secondary energy savings from decreased cooling loads are also at their greatest. Therefore, daylighting measures are a good way to achieve peak demand savings as well as energy consumption savings.

There are also a number of benefits from daylighting that are more difficult to quantify. There is a general trend in architecture today towards a "greening" of buildings. This trend includes adding daylighting features to new buildings, as well as other measures to improve the energy efficiency, improve indoor air quality and generally decrease the adverse environmental impacts of new buildings (Crosbie, 1994; Architectural Record, 1995). According to proponents of sustainable design, workers in daylit spaces generally prefer natural light to artificial lighting. Better lighting conditions can also lead to increased productivity and decreased sick leave.

1.6 Conclusion{ TC "1.6 Conclusion" \l 2 }

The energy used to heat and cool commercial buildings is a substantial portion of our overall energy expenditures in the U.S.. Because buildings have a long useful lifetime, the impact of the decisions that we make in constructing new buildings are paid for over many years. Thus the operating costs associated new buildings over their useful life may be more than the first cost of the buildings themselves.

Building codes have been used to insure that new buildings are constructed in an energy efficient manner. The Energy Policy Act of 1992 mandates that the 50 U.S. states update their building codes for commercial buildings. The act relies on ASHRAE Standard 90.1 - 1989 as the basis by which the state codes will be judged. The energy use implications of the enforcement of this standard may be great, but so far only a fraction of the states have met all the requirements of EPACT.

This thesis will help to quantify the benefits of the application of the ASHRAE standard. A case study of two existing commercial buildings will be used to assess the building envelope changes required by the standard. Computer simulations will be used to estimate the energy savings resulting from these envelope changes.

Daylighting has been suggested as a way to improve the energy efficiency of commercial buildings. There are many benefits to daylighting, the principal ones being energy savings from decreased reliance on electric lighting sources and associated energy savings from decreased cooling loads. The thesis will develop an estimate of these energy savings for the two case-study buildings, and compare those savings to those achieved by more traditional changes in the building envelopes required by building standards.