ENERGY MODELLING FOR BUILDINGS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF ARCHITECTURE

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled **"ENERGY MODELLING FOR BUILDINGS"** in partial fulfillment of the requirement for the award of Degree of Master of Architecture submitted in the Department of Architecture and Planning, Indian Institute of Technology, Roorkee, India is an authentic record of my own work carried out from May 2007 to June 2008 under the supervision of **Prof. P.K.Patel.**

The matter embodied in this dissertation has not been submitted by me for the award of any other degree

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This is to certify that the above statement made by the candidate is true and correct to the best of my knowledge.

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1.0 Introduction

A penny saved is a penny earned, they said. So with joules of energy! With recent exponential increases in energy pricing, the formerly neglected or underestimated concept of energy conservation has swiftly assumed great significance and potential in cutting costs and promoting economic development, especially in developing-country scenario like India. Reckless and unrestrained urbanization, with its haphazard buildings, has bulldozed over the valuable natural resources of energy, water, and ground cover, thereby greatly hampering the critical process of eco-friendly habitat development. However, it is not too late to retrace the steps. The resource crunch confronting the energy supply sector can still be alleviated by designing and developing future buildings on the sound concepts of energy efficiency and sustainability.

The 21st century is witnessing Urbanization and Industrialization at a very fast rate in India. In India, the rate of increase in generation of Electrical Energy has not been sufficient enough to meet the growing demand. The gap between the demand and supply is increasing with each passing day.

Therefore there is an urgent need to develop certain measures so that this gap between demand and supply is reduced. The buildings consume significant energy and hence the buildings need to be designed so that the consumption is reduced and energy is saved. The slogan also says "Energy saved is Energy generated".

India's building sector is growing fast – 20 million dwellings, 19 million sq m of commercial space, 13 million sq m of retail space, and 50,000 hotel rooms over the next five years.

Business-as-usual would mean a rapid increase in the sector's energy consumption, absorbing a growing proportion of India's incremental energy production in the years to come along with a necessary expansion of its energy infrastructure. On the other hand an energy-efficient development path would reduce overall energy use, pollution and CO_2 emissions. India's energy security would also improve.

The need of the hour is to reduce the consumption of the energy in the buildings. In this era of information technology the applications are becoming more and more computer based. New softwares are being made each day to provide tailor made solutions to the growing problems. The field of reducing consumption of energy in buildings has not remained untouched. The applications of these softwares help to find out not only the consumption of energy but also provides the solution by which it can be reduced. The area under study is an emerging area as regards the reduction of energy consumption in buildings; and relatively new for further research and understanding in the Indian context.

2.0 Objectives and Methodology

2.1 Identification of Problem

Buildings, as they are designed and used today, contribute to serious environmental problems because of excessive consumption of energy and other natural resources. The close connection between energy use in buildings and environmental damage arises because energy-intensive solutions sought to construct a building and meet its demands for heating, cooling, ventilation, and lighting cause severe depletion of invaluable environmental resources. However, buildings can be designed to meet the occupant's need for thermal and visual comfort at reduced levels of energy and resources consumption. Energy resource efficiency in new constructions can be effected by adopting an integrated approach to building design. The primary steps in this approach are listed below.

Incorporate solar passive techniques in a building design to minimize load on conventional systems (heating, cooling, ventilation, and lighting)

Design energy-efficient lighting and HVAC (heating, ventilation, and air-conditioning) systems

Use renewable energy systems (solar photovoltaic systems / solar water heating systems) to meet a part of building load

Use low energy materials and methods of construction and reduce transportation energy

Thus, in brief, an energy-efficient building balances all aspects of energy use in a building – lighting, space-conditioning, and ventilation – by providing an optimized mix of passive solar design strategies, energy efficient equipment, and renewable sources of energy. Use of materials with low embodied energy also forms a major component in energy efficient building designs.

Indian construction industry is one of the largest in terms of employing manpower and volume of materials produced (cement, brick, steel and other materials).

Construction sector in India is responsible for major input of energy resulting in the largest share of CO_2 emissions (22%) into the atmosphere. Apart from the office, commercial and industrial buildings, >2×106 residential buildings are built annually, in India. Demand and supply gap for residential buildings is increasing every year (20 million units in 1980 to 40 million units in 2000 Cement (>75 million tonnes per annum), steel (>10 million tonnes per annum) and bricks (>70 billion per annum) are the largest and bulk consumption items in the Indian construction industry. Minimizing the consumption of the conventional materials by using alternative materials, methods and techniques can result in scope for considerable energy savings as well as reduction of CO_2 emission.

If the techniques and the approach developed by TERI for energy-efficient buildings are applied to just 10% of the buildings constructed in cities every year, India can expect enough savings to light 20 million rural households.

Energy Efficiency has been recognized by the Government of India as a key to ensuring energy security. Extremely important to improve Energy Efficiency in different areas including Building Design and Construction, HVAC, lighting and Electric Appliances.

Energy efficiency is important for sustaining the current pace of economic growth. By applying Energy Codes 25%-40% of Energy can be saved (Bureau of Energy Efficiency, BEE)

Therefore we find that the buildings are being constructed with very little consideration towards energy saving in India and hence energy efficient design of the building is the need of the hour and retrofitting of those buildings is required which have are not energy efficient.

2.2 Objectives

A comprehensive overview of Key Issues and perspectives on Energy Efficiency in buildings and building codes. Familiarize with the Cost-benefits and mechanics of creating and implementing an Energy Code to understand greater energy efficiency in buildings. To understand the various aspects of building design by which energy consumption may be reduced. To learn the application of the Energy Conservation Building Code in different climates of India. Apply the ECBC with the help of computer software in buildings of composite climate ie in Delhi, Roorkee and nearby regions and then analyse the difference in the energy consumption.

2.3 Scope

In India the energy efficient buildings are negligible in number. As we know the major portion of the energy is being consumed in buildings especially which are centrally air conditioned. Therefore there is tremendous scope of reducing the energy consumption in buildings by applying ECBC and by considering features of building design itself, such as appropriate orientation, insulation, and shading – what is referred to as 'passive solar architecture' – can reduce energy requirements by about 10% and day-lighting, control systems, and energy-efficient lamps can bring them down by another 25%. Other important parameters which needs to be considered are Building Envelope, Heating Ventilation Air Conditioning (HVAC), Lighting and Controls.

2.4 Methodology

1. Literature study: data collection from Books, Journals, Internet and other sources.

2. Outline the need, aims and objectives, and scope of the study.

3. Case Studies: analysis of existing Energy Conservation Building Code compliant buildings in Composite Climate near Delhi and Roorkee.

4. Analysis and inferences from literature study and case studies.

5. Evaluation and Assessment of Energy Conservation Building Code compliant buildings.

6. Energy Modelling of Centrally Air Conditioned Central Library Building at IITRoorkee, Roorkee.

7. Energy Performance Report

8. Conclusions and recommendations.

3.0 Literature Study

3.1Energy Conservation Building Code- A brief description

Purpose

The purpose of this code is to provide minimum requirements for the energy-efficient design and construction of buildings.

Scope

The code is mandatory for commercial buildings or building complexes that have a connected load of 500 kW or greater or a contract demand of 600 kVA or greater. The code is also applicable to all buildings with a conditioned floor area of 1,000 m2 (10,000 ft2) or greater. The code is recommended for all other buildings.

Applicable Building Systems

The provisions of this code apply to:

(a) Building envelopes, except for unconditioned storage spaces or warehouses,

(b) Mechanical systems and equipment, including heating, ventilating, and air-conditioning,

(c) Service hot water heating,

(d) Interior and exterior lighting, and

(e) Electrical power and motors.

Exemptions

The provisions of this code do not apply to:

(a) Buildings that do not use either electricity or fossil fuel,

(b) Equipment and portions of building systems that use energy primarily for manufacturing processes, and

(c) Multi-family buildings of three or fewer stories above grade, and single-family buildings.

Safety, Health and Environmental Codes Take Precedence

Where this code is found to conflict with safety, health, or environmental codes, the safety, health, or environmental codes shall take precedence.

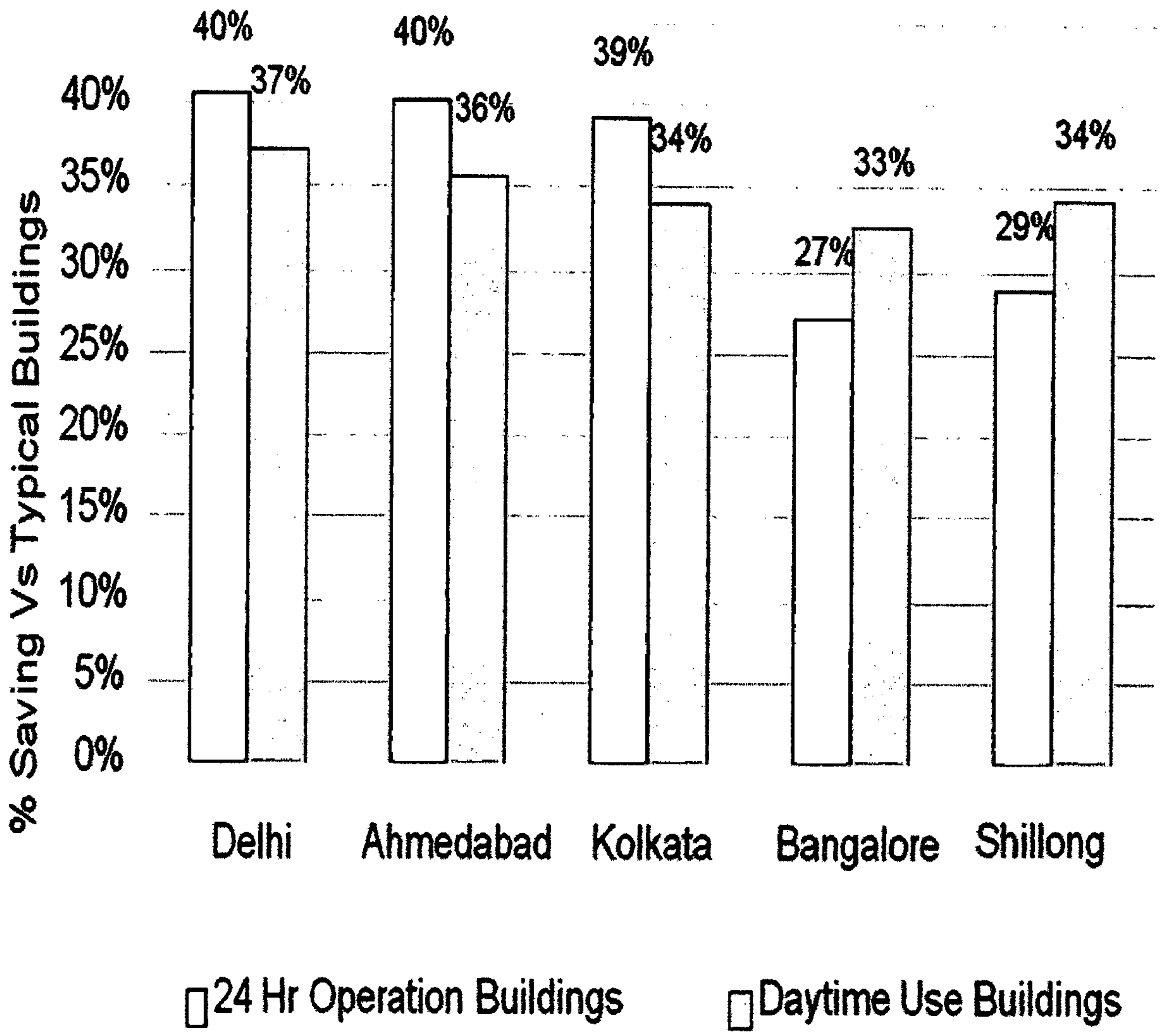
- Features of building design itself, such as appropriate orientation, insulation, and shading – what is referred to as 'passive solar architecture' – can reduce energy requirements by about 10% and day-lighting, control systems, and energy-efficient lamps can bring them down by another 25%.
- A TERI study of 18 premier hotels in India found that energy conservation measures can lower electricity bills by 15% to 20%.

The share of electricity consumption of large buildings in the commercial sector is currently of the order of 7 percent of country's overall consumption, and it is growing at about 12 per cent over the last few years. Annual energy consumption in commercial buildings, which is in excess of 200 kWh per square meter of floor area, is expected to be brought down to 120-160 kWh when the standards are implemented. According to Construction Industry Development Council (CIDC), residential and commercial construction has been growing in excess of 10 percent per annum, and that accounted for nearly 41 million square meters last year

3.2National Impact Potential

Tremendous savings can be expected in modern high-rise urban buildings. The average energy use for typical commercial building is 200 kWh/sq. meter/year. Mandatory enforcement of ECBC can reduce the energy use by 30-40% to 120-160 kWh/sq. meter/year. Nationwide Mandatory enforcement of ECBC would have yielded a saving of 1.7 billion kWh for 2005-2006. (BEE)

Energy Saving



3.3 Energy Distribution in Buildings

Energy in buildings can be categorized into two types:

(1) Energy for the maintenance/servicing of a building during its useful life, and

(2) Energy capital that goes into production of a building (embodied energy) using various building materials.

Study of both the types of energy consumption is required for complete understanding of building energy needs. Embodied energy of buildings can vary over wide limits depending upon the choice of building materials and building techniques. RC frames, RC slabs, burnt clay brick masonry, concrete block masonry, tile roofs represent common conventional systems forming the main structure of buildings in India. Similar building systems can be found in many other developed and developing countries. Alternative building technologies such as stabilized mud blocks (SMB's), prefabricated roofing systems, masonry vaults, filler slab roofs, lime-pozzolana (LP) cements, etc. can be used for minimizing the embodied energy of buildings.

Embodied energy can be split into: (1) energy consumed in the production of basic building materials, (2) energy needed for transportation of the building materials, and (3) energy required for assembling the various materials to form the building. The following aspects of embodied energy are important:

1. Energy consumption in building materials.
2. Energy in transportation of building materials.
3. Energy in different types of buildings and building systems.

It is hoped that the information provided here could help in selecting energy efficient building technologies and building systems based on embodied energy thereby reducing cost of materials as well as CO2 emission into atmosphere.

Energy in building materials:

Basic building materials

Energy consumed during production of basic building materials is given in Table 1. These energy values pertain to production systems employed by the material manufacturers in India. Total energy values of various basic materials given in Table 1 have been used in the computations of energy in building materials/systems and buildings.

Table 1. Energy in basic building materials

Type of material	Thermal energy (MJ/kg)
Cement	5.85
Lime	5.63
LP	2.33
Steel	42.0
Aluminium	236.8
Glass	25.8

Portland cement represents one of the major materials consumed in bulk quantities for building construction. Energy of cement arises from the use of coal in the rotary kilns and energy needed for crushing and grinding the clinker. In India, cement is manufactured by employing both the wet (old cement plants) and dry (new plants) process. Wet process used in earlier cement plants leads to an energy consumption of 7.5 MJ/kg of cement, whereas modern plants employing precalcination and dry process consume 4.2 MJ/kg of cement. The value of 5.85 MJ/kg of cement given in Table 1 represents the average value of 7.5 and 4.2 MJ. The average value of 5.85 MJ/kg of cement has been used in the computation of energy in various components and systems. A report on energy in buildings compiled by Development Alternatives gives a value of 5.75 MJ/kg for cement manufacture.

Hydrated lime consumes 5.63 MJ of thermal energy/kg, which is about the same as that for cement. High-energy consumption for lime can be attributed to low thermal efficiency of small-scale kilns employed for lime burning in India.

LP cements can provide very effective alternative to Portland cement, mainly for secondary applications such as masonry mortar, plastering, base/sub-base for flooring, etc. A typical LP cement will consists of 30% lime, 60% pozzolana and during the burning process. Coal, coal cinder and firewood are the most commonly used fuels for brick burning in India. In general, each brick needs either 0.20 kg of coal or 0.25–0.30 kg of firewood for the burning process. This translates into a thermal energy of 3.75–4.75 MJ per brick. An average value of 4.25 MJ per brick (size: 230 mm×110 mm×70 mm) has been considered for the comparison and computation of energy content of buildings and masonry.

Hollow concrete blocks

These are light weight/low density blocks very commonly used for the construction of non-load bearing filler walls in multi-storeyed buildings in India. They are also used for the construction of load bearing masonry walls to a limited extent. The basic composition of the blocks consists of cement, sand and coarse aggregates (~6 mm size). The energy content of the block will mainly depend upon the cement percentage. Energy spent for crushing of coarse aggregate will also contribute to the block energy. The cement percentage generally varies between 7 and 10% by weight. Quality of the block, particularly compressive strength is the deciding factor for cement percentage. Energy content of the hollow concrete block of size 400 mm×200 mm×200 mm will be in the range of 12.3–15.0 MJ.

Soil–cement blocks

These are produced by pressing a wetted soil–cement mixture into a solid block using a machine (manually operated or mechanized) and then cured. Soil–cement blocks produced by employing manually operated machines in a highly decentralized fashion have become increasingly popular in India and elsewhere. Energy content of the blocks is mainly dependent upon the cement content. Soil–cement blocks used for the load bearing masonry buildings will have cement content of about 6–8%. Such blocks will have an energy content of 2.75–3.75 MJ per block of size 230 mm×190 mm×100 mm.

Steam cured mud blocks

These are lime stabilized blocks using expansive and high clay soils. They are produced by mixing suitable proportion of lime, clayey soil and sand and then pressing into a block of convenient size. The blocks produced in this manner are cured in a steam chamber at about 80 °C for 10–12 h. The steaming process accelerates lime–clay reactions and the block is ready for construction within 2 days after moulding. Steam curing operations involve extra energy expenditure. Total energy required will be about 6.70 MJ per block of size 230 mm×190 mm×100 mm using 10% lime.

Energy content of different types of blocks used for masonry construction is given in Table 2. The table gives details of block type, size, energy content, energy per brick equivalent and percentage of energy with respect to brick energy. The blocks are of different size; hence they have been normalized by referring to an equivalent brick size. The following points are clear from the data given in the table.

1. Stone blocks do not consume any thermal energy, whereas burnt clay bricks consume maximum amount of energy among the alternatives shown in the table.
2. Soil–cement block with 6% cement is the most energy efficient block consuming only 23.5% of burnt clay brick energy.
3. Soil–cement block and hollow concrete block with 7–8% cement have similar embodied energy values, i.e. about 30% of the burnt clay brick energy.
4. Steam cured mud blocks consume about 60% of burnt clay brick energy. This can be attributed to high percentage of lime and fuel used for steaming operations.

Table 2. Energy in masonry materials

Type of material	Size (mm)	Energy in one brick/blocks (MJ)	Energy per brick equivalent (MJ)	(Block energy) (brick energy) (%)
Stone block	180 x 180 x 180	0	0	0
Burnt clay brick	230 x 105 x 70	4.25	4.25	100
Soil–cement block	230 x 190 x 100	2.60 (*6% cement*)	1.00	23.5
	230 x 190 x 100	3.50 (*8% cement*)	1.35	31.7
Hollow concrete block	400 x 200 x 200	12.30 (*7% cement*)	1.32	31.2
	400 x 200 x 200	15.00 (*10% cement*)	1.62	38.1
Steam cured block	230 x 190 x 100	5.70 (*10% lime*)	2.58	60.6

Energy in transportation of building materials

Transportation of materials is a major factor in the cost and energy of a building. Bulk of the building materials in urban and semi-urban centers are transported using trucks in India. The transportation distance may vary depending upon the location of construction activity. In urban areas, the materials travel anywhere between 10 and 100 km in the Indian context. Materials such as sand are transported from a distance of 70–100 km in cities like Bangalore, India. Similarly bricks/blocks, crushed aggregate, etc. travel about 40–60 km before reaching a construction site, in urban and semi-urban centers.

Cement and steel travel even longer distances, of the order of 500 km or more. Long haul of cement and steel is handled through rail transport. Fancy building materials such as marble, paints, etc. are sometimes transported from great distances (>1500 km) in India.

Natural sand and crushed stone aggregate consume about 1.75 MJ/m3 for every one km of transportation distance. Similarly bricks require about 2.0 MJ/m3 per km travel. Assuming steel and cement are also transported using trucks, diesel energy of 1 MJ/tonne/km is spent during transportation. Table 3 gives diesel energy spent during transportation of various building materials, along with the energy consumed in production. Thermal energy spent for natural sand production is nil, but it requires about 175 MJ of diesel energy/m3 for transporting it over 100 km distance. Crushed aggregate consumes about 20 MJ/m3 during its production and an additional 400–800% more during transportation for distances of 50–100 km. The energy spent during transportation of bricks is about 4–8% of its energy in production, for distances of 50–100 km. Transportation energy required for hauling high-energy materials such as steel and cement is marginal when compared to the energy spent during production.

Table 3 Energy in transportation of building materials

Number	Type of material	Energy (MJ)		
		Production	Transportation	
			50 km	100 km
1	Sand (m^3)	0.0	87.5	175
2	Crushed aggregate (m^3)	20.5	87.5	175
3	Burnt clay bricks (m^3)	2550	100	200
4	Portland cement (tonnes)	5850	50	100
5	Steel (tonnes)	42000	50	100

Energy in mortars

Mortar is a mixture of cementitious material and sand. It is used for the construction of masonry as well as plastering. Cement mortar, cement–soil mortar, cement–pozzolana mortar are used for masonry construction and plastering. Cement mortar is a common choice for masonry and rendering works. Cement–soil mortar has been used for the construction of SMB masonry. Cement–pozzolana and LP mortars can also be used for masonry construction and other applications. Total energy content of these four types of mortars is given in Table 4. Details of mortar type, their proportions and energy content/m3 of mortar are given in this table. The following observations can be made from the data given in the table.

1. Cement mortar consumes more energy than other types of mortars.

2. Replacing 20% of cement by pozzolana leads to a 25% reduction in energy of cement mortar.

3. Dilution of cement mortars by the addition of soil, leads to more than 25% savings in the energy content of mortar. It is to be noted here that cement–soil mortars are economical and have better characteristics than pure cement mortars. They have better plasticity, adhesion/bond leading to higher values of masonry compressive strength.

4. LP mortar has the lowest energy value when compared with other mortars.

Table 4 Energy in different types of Mortar

Type of mortar	Proportion of materials			Energy/m³ (MJ)
	Cement	Soil	Sand	
Cement mortar	1	0	6	1268
	1	0	8	1006
Cement pozzolana mortar	0.8:0.2[b]	0	6	918
	0.8:0.2[b]	0	8	736
Cement–soil mortar	1	2	6	849
	1	2	8	773
LP mortar	1 (1:2)[c]	0	3	732

Energy in different types of masonry

Masonry is an assemblage of masonry units (such as bricks/blocks) and mortar. Individual volumes of these two components in masonry will depend mainly upon the size of masonry unit. Energy content of masonry should include energy content of masonry units as well as mortar. Table 5 gives energy content of 4 types of masonry. Energy/m3 of masonry as well as equivalent of brick masonry energy has been reported. Cement mortar (1:6) for brick masonry and hollow concrete block masonry and cement–soil mortar (1:2:6) for soil–cement block masonry and steam cured mud block masonry, has been considered for calculating the energy content of masonry.

Table 5. Energy in different types of masonry

Number	Type of masonry	Energy/m³ of masonry (MJ)	Equivalent of brick masonry energy (%)
1	Burnt clay brick masonry	2141	100.0
2	Hollow concrete block masonry	819 (7% cement blocks)	38.3
		971 (10% cement blocks)	45.4
3	Soil–cement block masonry	646 (6% cement blocks)	30.2
		810 (8% cement blocks)	37.8
4	Steam cured mud block masonry	1396 (10% lime blocks)	65.2

Energy content of brick masonry is the highest with a value of 2141 MJ/m3. Soil–cement block masonry consumes only about one-third of brick masonry energy. Hollow concrete block masonry requires about 38–45% of the brick masonry energy. Steam cured mud block masonry consumes about two-thirds of that needed for brick masonry. Soil–cement block masonry is the most energy efficient among the alternatives listed in the table.

Energy in different types of floor/roofing systems

Varieties of alternatives are available for the construction of roof/floor of a building. Energy content and construction details of some of the roof/floor systems have been discussed in the following sections. These alternative systems have been used for construction of buildings in India.

Stabilised mud block (SMB) filler slab roof

RC solid slab is very commonly used for the floor slab as well as roof slab construction. A portion of the material below neutral axis in a solid slab can be replaced by filler material such as SMB. Use of such filler material can result in reduction in dead weight of RC slab, savings in cost as well as energy of the roof/floor system. Fig. 1 shows the ceiling of a SMB filler slab roof. The total energy content of the materials constituting SMB filler slab is 590 MJ/m2 of plan area of the slab. This is a floor slab designed as per IS 456 code [23], for a span of 3.6 m. There will be variations in energy content for different span of the slabs.

Fig. 1 Ceiling of a typical SMB filler slab roof.

Composite brick panel roof/floor slab

This roof consists of a reinforced brickwork panel supported on RC beams as shown in Fig. 2. Size of RC beams will depend upon their spacing and roof span. Both the panels as well as RC beam can be precast and assembled into a roof slab.

The energy content of such a slab for 3.6 m span is about 560 MJ/m2 of projected plan area of the slab.

Fig.2 Ceiling of a typical reinforced brickwork panel roof.

Masonry vault roof

The figure 3 shows an unreinforced masonry vault roof. It consists of a thin masonry vault supported on ring beams with tie rods. Vault can be constructed using burnt clay bricks or SMB's. Total energy/m2 of plan area of the roof will be 575 and 418 MJ for brick masonry and SMB masonry vault roofs respectively.

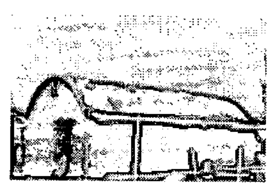


Fig 3 Unreinforced masonry vault roof

Ferroconcrete tile roof

Fig. 4 shows a ferroconcrete tile roof. Ferroconcrete tile can be made locally using thin galvanised iron (GI) wires and microconcrete. The tile size is about 1.25 m×0.55 m. These tiles can be supported on wooden rafters. The energy/m2 of such a roof is 158 MJ.

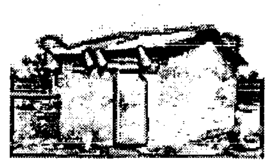


Fig 4 Ferroconcrete tile roof building

Energy values of different types of floor/roofing systems are given in Table 6. The table gives energy/m2 of plan area of roof/floor and an equivalent of RC slab energy. The following points can be summarised from the data given in the table.

1. RC solid slab roof/floor consumes highest amount of energy, whereas ferroconcrete tile roof is the least energy roof.

2. Use of SMB filler in RC slab leads to about 20% reduction in energy content.

3. Composite brick panel roof and brick masonry vault roofs have approximately similar energy values. The energy content of such roofs/floors is about three-fourth that of RC slab energy.

4. RC ribbed slab roof system consumes about two-thirds of energy of RC slab roof/floor. This is another efficient way of reducing energy of RC solid slab.

5. Brick masonry vault consumes 575 MJ/m2 of plan area, which is about 80% of RC solid slab energy. Substituting brick with SMB makes the vault more energy efficient.

6. Mangalore tile roof is one of the least energy consuming among the traditional roofing systems. Its energy content is about 30% of the RC slab energy. Ferroconcrete tile roof, an alternative to Mangalore tile roof needs only about 158 MJ/m2, which is 30% less than that of Mangalore tile roof energy.

Table 6. Energy in different roofs/floor systems (span = 3.6 m)

Number	Type of roof/floor	Energy/m^2 of plan area (MJ)	Equivalent of RC solid slab energy (%)
1	RC slab	730	100.0
2	SMB filler slab roof	590	80.8
3	RC ribbed slab roof	491	67.3
4	Composite brick panel roof	560	76.7
5	Burnt clay brick masonry vault roof	575	78.8
6	SMB masonry vault roof	418	57.3
7	Mangalore tile roof	227	31.1
8	Ferroconcrete roof	158	21.6

The information provided in Table 6 can be used conveniently for making a selection of roofing system based on energy content of the roof/floor system.

3.4 Conclusions

The following broad conclusions emerge.

1. Soil–cement block is the most energy efficient among the alternative materials for walling, consuming only one-fourth of the energy of burnt clay brick. Concrete blocks and steam cured blocks also consume much less energy during manufacturing process, when compared to burnt clay brick.

2. Building materials are transported over distances in excess of 100 km in many urban centres in India. Diesel energy spent for transportation could be about 5–10% of energy spent during manufacturing process for burnt clay bricks. Energy spent in transporting high-energy materials like steel and cement is negligible when compared to the energy spent in the manufacture of these materials.

3. LP mortars have lowest energy content when compared with other mortars like cement mortar, cement–pozzolana mortar, etc.

4. Energy content of burnt clay brick masonry is 2141 MJ/m3. Soil–cement block masonry is most energy efficient at one-third the energy of burnt clay brick masonry. Concrete block masonry has about 40–45% of energy content of burnt clay brick masonry.

5. Use of SMB filler blocks in solid RC roof/floor slabs leads to 20% reduction in energy content. Masonry vault roofs are more energy efficient than solid RC slab. Tile roofs have least energy content when compared with other roofing systems.

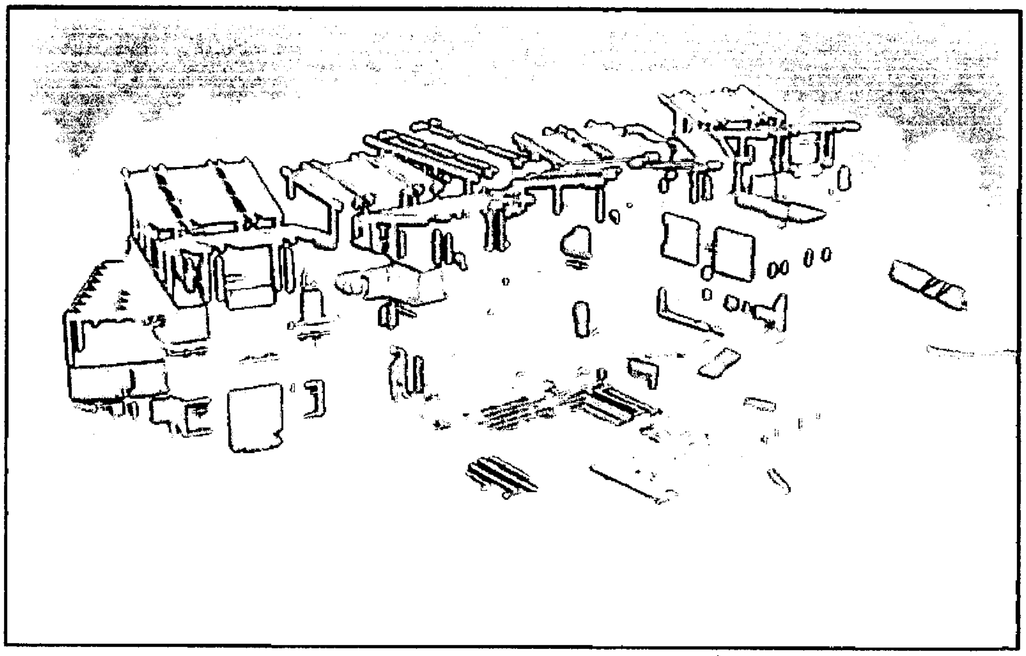
6. Embodied energy of multi-storeyed RC framed structure building is the highest at 421 GJ (21 tonnes of coal equivalent)/100 m2 built-up area. Building with load bearing masonry structure using burnt clay bricks and RC slab has 30% less embodied energy when compared to RC framed structure building.

7. Use of energy efficient alternative building technologies can result in considerable reduction in the embodied energy of the buildings. Load bearing soil–cement block masonry and SMB filler slab has resulted in 62% reduction in embodied energy when compared to RC framed structure building and 45% reduction when compared with burnt clay brick masonry and RC solid slab building.

4.0 Case Studies

4.1 Case Study -1

Centre for Environmental Sciences and Engineering Building, IITKanpur, Kanpur.



- Client: IITKanpur, Kanpur
- Architect: Kanvinde Rai & Chowdhury
- Energy Consultant: TERI
- HVAC Consultant: Gupta Consultants and Associates
- Electrical Consultant: Kanwer Krishen Associates Pvt. Ltd.

Energy Efficiency and Green Features in the Building

- The site for the building has full grown mature trees most of which were protected and preserved
- The building is fully compliant with ECBC

- Solar passive architectural design strategies are adopted and all the laboratory spaces would be naturally lit during the day time
- Rain water harvesting is done and treated waste water is reused for irrigation.

Energy Modelling

Introduction

The study presented here is mainly related to criterion **13** in TERI GRII4A, which is based on energy consumption in buildings. The criterion is performance based and sets a benchmark energy consumption figure of **140** kWh per m2 per year, which can be achieved through various energy efficiency measures. This benchmark is applicable to air-conditioned areas of daytime (9 am to 5 pm) occupied buildings in composite climate, which is the case in IIT Kanpur. Attaining the benchmark of **140** kWh per m2 per year fetches **2** points and additionally, every 10% decrease from the benchmark fetches additional **2** points for a maximum of **10** points.

The study here analyses the effect of various building components on the annual energy consumption of the building. This would lead to a comparison of the energy consumption in air-conditioned areas of IIT Kanpur building with the benchmark energy consumption of TERI GRIHA. The building components include the following:

1. Building envelope
   - Wall
   - Roof
   - Glass
   - Shading
2. Building systems
   - Lighting
   - Air-conditioning

Methodology of Study

The study methodology involves creation of a *base case* and then applying various energy efficiency measures and then applying various energy efficiency measures and calculating the annual energy consumption in each case. Thus the improvements achieved through each of the measures were quantified and the final energy consumption figure for air- conditioned areas of the building was established. This was compared with the benchmark figure of TERI GRIHA to determine the total reduction achieved from the benchmark figure.

Simulations were carried out through the software VisualDOE **4.1**, with DOE **2.1E** as the simulation engine. The software performs hourly calculations to arrive at the annual energy consumption.

The study was divided into **2** main stages:

1. Optimization of building envelope

At this stage, the model of the building is created in VisualDOE using inputs from the architect and the user group. Default values are used for inputs like HVAC systems, light power density, etc. All parameters for HVAC systems are default values and the capacities of the systems and the central plant are auto sized (i.e. calculated by the software). Therefore what is important at this stage is the relative reduction in the plant capacity and energy consumption due to different options of the building envelope. Through this analysis, the building envelope is optimized for air-conditioned areas of the building.

2. Optimization of building systems

Once the building envelope is decided, the U-values corresponding to the components are provided to the HVAC consultant and these would be used for designing the UVAC system for the building. Meanwhile, optimized values of light power density based on lighting analysis would also be used as inputs to the model. The final energy consumption figure would be established for air-conditioned areas of the building.

Definition of the Base case

- *Base* case is the initial design of the building and the systems in the building, without incorporation of energy efficiency measures. The building components for the base case are described below in table 7:

Table 7: Building components for the base case

	Construction	U-factor
Wall	Cavity Brick	0.27Btu/hr ftsqF
Roof	Concrete	0.45 Btu/hr ftsqF
Glass	----------	0.28 Btu/hr ftsqF
Shading Coefficient	----------	0.47
Visible light transmittance	---------	0.62

Modifications were made to this case and the reduction in energy consumption was quantified. The analysis is presented in the following sections.

Optimization of building envelope

Optimization of the building envelope was made by analysis various options of insulation for walls and roof. The basis of selecting different options of insulation is to achieve U-values recommended by the draft Energy Conservation Building Code (ECBC) **2005.** ECBC recommends the maximum U-values for different building components for different climatic zones of India. The upcoming buildings at IIT Kanpur are classified under the daytime occupied building category, and in composite climate.

The recommended specifications of the building components for these conditions are given in the table 8 below.

Parameter	Specification
Wall assembly	0.062 Btu/hrft2F
Roof assembly	0.072Btu/hrft2F
Glass	0.56 Btu/hrft2F
Solarheatgaincoefficient(inclshading)	0.25

It has to be noted that the external shading for windows was optimized through shading analysis, and the optimized shading has been used in the analyses here. Also the glass type would remain the same for all the options presented here. The following options were analyzed for the envelope.

Table 9

	Material	Thickness	U-factor of wall/roof
Wall construction			
Wall 1	Mineral Wool	2.0"	0.093
Wall 2	Expanded polystyrene	2.0"	0.091
Wall 3	Extruded polystyrene	2.0"	0.078
Roof construction			
Roof 1	Perlite	3.2"	0.070
Roof 2	Insuplast	2.0"	0.066

The energy analysis for the various options of envelope is presented in the table below. The total kWh energy consumption consists of lighting and air-conditioning energy consumption. The energy consumption of other equipments are excluded because they are not related to thermal or visual comfort, and are entirely defined by the functionality of the building.

The final components of the envelope and their properties are given in the table 10 below:

Wall	Cavity wall with 2"	U 0.091 Btulhr 112 F
	Expanded polystyrene in	
	the cavity	
Roof	4.7" Concrete with fibre glass under deck insulation	U :0.100 Btu/hr ft2 F
Glass	U 0.282 Btu/hr ft2 F	
	Shading co efficient = 0.47 Visible light transmittance : 0.62	

Optimization of building systems

The air conditioning system designed by the consultant was defined in the simulation model to demonstrate the actual case and predict the annual energy consumption of the building. The light power density values used in the model were obtained from the lighting analysis. The operating schedules of the different rooms in the building, the air-conditioning system, etc. were defined in the model as per the consultants and the user group. The annual energy consumption has been calculated for air-conditioned areas. The following sections explain the methodology, parameters used and the results of the building energy performance analysis

Description of the case

The air-conditioned area of the building is 168 m2. A few areas on the ground floor and all areas on the first floor are proposed to be air-conditioned. Air-conditioning of larger areas like laboratories and classrooms are proposed to be through Air Handling Units and the smaller areas like faculty rooms are proposed to have fan coil units. The air-conditioning system designed by the HVAC consultant consists of a chiller and thermal energy storage. The main purpose of thermal energy storage would be to serve as standby cooling energy in case of power failure. The thermal storage can provide cooling with minimum energy requirements (for the pumps) for critical laboratories. Four different options of the cooling system were provided by the HVAC consultant. The corresponding parameters were used as inputs in the simulation model and the energy performance of the building was calculated. The input parameters provided by the consultant for the 4 different options are mentioned in the table 11 below:

Parameter	Value				Units
	Option-I	Option-II	Option-III	Option-IV	
CHILLER					
Suction temp at beginning of ice making	26 deg F	26 deg F	26 deg F	26 deg F	
Drop in suction temperature	16 deg F	16 deg F	16 deg F	16 deg F	
Chiller Type	Screw	Screw	Scroll	Screw	
Chiller size & Nos.	57	73	68	92	Tons
Full load efficiency	0.75	0.74	0.71	0.74	kW/Ton
Minimum operating poing	0.3	0.3	0.3	0.3	
Evaporator pump					
Flow	2.4	2.4	2.4	2.4	gpm/ton
Primary loop pressure drop	40	40	40	40	Ft
Impeller efficiency	0.77	0.77	0.77	0.77	
Motor efficiency	0.9	0.9	0.9	0.9	
Chilled water δT	10	10	10	10	ºF
Condenser Pump					
Flow	3.8	3.8	3.8	3.8	gpm/ton
Condenser water loop pressure drop	79	79	79	79	Ft
Impeller efficiency	0.77	0.77	0.77	0.77	
Motor efficiency	0.9	0.9	0.9	0.9	
Condenser water δT	7.7	7.7	7.7	7.7	ºF
Evaporator Pumkp (Secondary Loop					
Type of conrol	------------------------Variable Speed------------------------				
Pump head	59	59	59	59	Ft
Impeller efficiency	0.8	0.8	0.8	0.8	
Motor efficiency	0.9	0.9	0.9	0.9	
Minimum operating Point	0.3	0.3	0.3	0.3	
Loop design δT	10	10	10	10	ºF

Sizing based on	----------------Installed plant equipment----------------				
Parameter	Value				**Units**
	Option-I	**Option-II**	**Option-III**	**Option-IV**	
COOLING TOWER					
Type	Open	Open	Open	Open	
Cells					
Number of cells	----------------Minimum cells needed----------------				
Control	0.33	0.33	0.33	0.33	
Minimum % design flow per cell	2	2	2	2	
Temperatures					
Design WBT	78	78	78	78	ºF
Approach temperature	8	8	8	8	ºF
Design range	10	10	10	10	ºF
Fan bhp/ton	0.0127	0.0127	0.0127	0.0127	
Motor efficiency	0.9	0.9	0.9	0.9	
Temperature control	----------------Fixed temperature----------------				
Setpoint temperature	85	85	85	85	ºF
Throttling range	10	10	10	10	ºF
Capacity control	----------------One Speed Fan----------------				

Additionally, the light power densities from optimized lighting design were also used in the model. (Refer lighting chapter for details). Simulations in VisDOE provided the following results for the four options

Alternative	**Lights kWh**	**HVAC kWh**	**Annual kWh**
Option 1	29,424	162,495	191,919
Option 2	29,424	157,536	186,960
Option 3	29,424	155,654	185,078
Option 4	29,424	155,389	184,813

Energy savings due to the use of earth air tunnel

The fresh air to the AHUs is the air from the outlet of the earth air tunnels. This enables cooling load reduction as the fresh air supplied to the AHUs is at a lower temperature than the ambient temperature. This was incorporated in the HVAC load calculations and as per the consultant's design, has enabled reduction in cooling load by i8 tons. This parameter has been used along with the chiller efficiencies to calculate the reduction in energy consumption in each of the options.
It has to be noted here that the earth air tunnel cannot be defined in the simulation software, and therefore manual calculations were required as shown below in Table 12

Alternative	TR	Operating hours/yr	IIWITR	Diversity	kWh savings per year
Option 1	18	2080	075	0.6	16848
Option 2	18	2080	0.74	0.6	16623
Option 3	18	2080	0.71	0.6	15949
Option 4	18	2080	0.74	0.6	16623

Accordingly, the final building energy consumption and energy index have been calculated and tabulated below in Table 13.

Alternative	Annual kWh (lighting + HVAC)	Energy index KWh/m² yr
Option 1	175,071	106.9
Option 2	170,337	104.0
Option 3	169,129	103.3
Option 4	168,190	102.7

The final option selected was option **2,** i.e. a screw chiller of capacity 73 TR and a thermal energy storage of capacity **230** ton-hrs, and able to provide **30** tons of cooling load as per requirements.

4.2 Case Study-2
Fortis Hospital Building, Shalimarbagh, New Delhi.

- Client: Fortis Healthcare Ltd.
- Architect: Mani Chowfla Associates
- Energy Consultant: TERI
- HVAC Consultant: DewPoint Consultants
- Electrical Consultant: TS Sethi, Design Engineering Partners

Brief description

The Forth hospital at Shalimarbagh, New Delhi, is being designed with a vision to provide an environment friendly health care facility. The hospital has been planned as a 500-bed facility that would cover a built up area of 64 400 sq mts, comprising cardiology, renal, and gastro intestinal units. Energy efficiency and resource conservation measures will be incorporated in various aspects of the design, construction, and operation of the proposed green building. The hospital is being designed as an energy efficient building that complies with the ECBC (Energy Conservation Building Code) and is undergoing

TERI-GRIHA (Green Rating for Integrated Habitat Assessment) rating certification. It is the first hospital building in India to have registered for the building rating system.

Energy efficiency and green features in the building

- The building would comply with the ECBC.
- Low embodied energy material options are being explored by Fortis management.
- As a commitment to control ozone-depleting substances in the atmosphere, the Fortis hospital would install CFC (chlorofluorocarbon) and HCFC
- Sustainable site planning is practiced on site to conserve resources, minimize disruption of the natural ecosystem, and maintain the microclimate of the site.
- The building design has been optimized to reduce the external solar gains and avoid over design of lighting and air-conditioning systems.

Building performance on compliance with the Energy Conservation Building Code

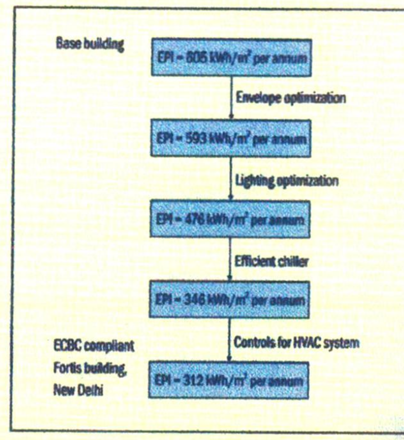
Following the recommendations of the ECBC of the Bureau of Energy Efficiency, Government of India, several energy efficiency strategies have been adopted at the Fortis hospital. This section compares a base building with the ECBC compliant building.

	Base building	Fortis hospital, Delhi
	1. Building envelope	
External wall	230 mm brick work plastered on both sides U-value = 1.98 W/m²K	Cement plaster + 200 mm AAC blocks + cement plaster U-value = 0.69 W/m²K
Roof	150 mm concrete roof slab + 100 mm brick coba + roof tile finish U-value = 2.43 W/m²K	150 mm RCC + 65 mm vermiculite + 100 mm brick coba + 25 mm tiles U-value = 0.98 W/m²K
Glass	Single clear 6mm glass U-value = 5.7 W/m²K SHGC = 0.85 Light transmittance = 89%	Double glazed low emissivity glass U-value = 2.8 W/m²K SHGC = 0.46 External shading designed to reduce SHGC to 0.25 Light transmittance = 46%
	EPI = 605 kWh/m² per annum	EPI = 593 kWh /m² per annum (2% reduction) after building envelope optimization
	2. Lighting	
	LPD = 20 W/m².	LPD achieved is less than 10 W/m² Energy efficient fixtures and lamps have been used
	EPI = 605 kWh/m² per annum	EPI = 476 kWh /m² per annum (21% reduction) after building envelope + lighting optimization
	3. HVAC	
	Chiller efficiency = 1.15 KW/TR Air cooled chiller	Chiller efficiency = 0.61 KW/TR Water cooled screw chiller has been used
	EPI = 605 kWh/m² per annum	EPI = 346 kWh /m² per annum (43% reduction) after building envelope + lighting + efficient chiller as per ECBC
	4. Controls for HVAC system	
	None	Variable frequency drive on chilled water pumps, air handling units
	EPI = 605 kWh/m² per annum	EPI = 312 kWh /m² per annum (48% reduction) after building envelope + lighting + HVAC optimization + controls

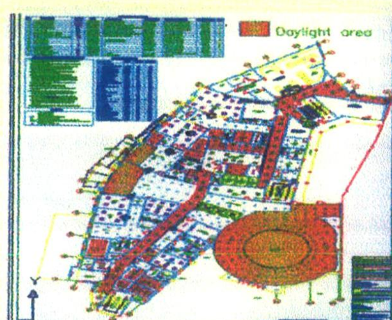
AAC - autoclaved aerated concrete; ECBC - Energy Conservation Building Code; EPI - Energy Performance Index; HVAC - heating, ventilation, and air-conditioning; LPD - lighting power density; RCC - reinforced cement concrete; SHGC - solar heat gain coefficient

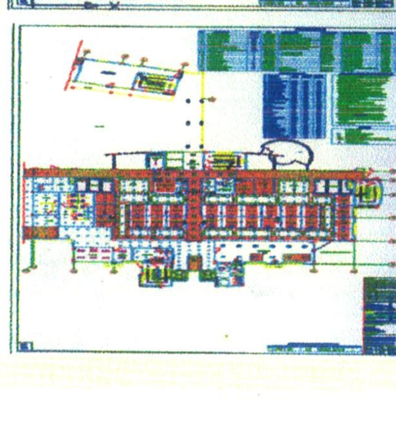
EPI includes lighting and cooling electricity consumption only

Energy savings achieved through ECBC interventions



Lighting simulations carried out to integrate daylight with artificial lighting





5.0 Building Envelope

5.1 Introduction

Building "Envelope" generally refers to those building components that enclose conditioned spaces and through which thermal energy is transferred to or from the outdoor environment. The thermal energy transfer rate is generally referred to as "heat loss" when we are trying to maintain an indoor temperature that is greater than the outdoor temperature. The thermal energy transfer rate is referred to as "heat gain" when we are trying to maintain an indoor temperature that is lower than the outdoor temperature.

Ultimately the success of any facility-wide energy management program requires an accurate assessment of the performance of the building envelope. This is true even when no envelope-related improvements are anticipated. Without a good understanding of how the envelope performs, a complete understanding of the interactive relationships of lighting and mechanical systems cannot be obtained.

In addition to a good understanding of basic principles, seasoned architects, engineers and analysts have become aware of additional issues that have a significant impact upon their ability to accurately assess the performance of the building envelope.

1. The actual conditions under which products and components are installed compared to how they are depicted on architectural drawings.

2. The impact on performance of highly conductive elements within the building envelope; and

3. The extent to which the energy consumption of a building is influenced **by** the outdoor weather conditions, a characteristic referred to as *thermal mass.*

5.2 Quantifying Building Envelope Performance

The rate of heat transfer through the building envelope will be found to be related to the following important variables:

1. Indoor and outdoor temperature;
2. Conductivity of the individual envelope components; and
3. The square footage of each of the envelope components.

For a particular building component exposed to a set of indoor and outdoor temperature conditions, these variables are often expressed in equation form by the following:

$$q = UA\ (T1 - T0) \qquad (5.1)$$

Where:

q = the component heat loss, 8w/hr

U = the overall heat transfer coefficient, Btu/ (hr-ft2-°F)

A = the area of the component, ft2

T = the indoor temperature, °F

T0 = the outdoor temperature, °F

5.3 Principles of Envelope Analysis

The successful evaluation of building envelope performance first requires that the analyst be well-versed in the use of a host of analytical tools which adequately address the unique *way* heat is transferred through each component. While the heat loss principles are similar, the calculation will vary somewhat from component to component.

5.4 Metal Elements in Envelope Components

Most commercial building construction is not wood-framed. Economics as well as the need for fire- rated assemblies has increased the popularity of metal- framing systems over the years. The conductivity of metal framing is significantly more than an order of magnitude greater than the insulation it penetrates. In some instances it is several thousand times greater However, until recent years, the impact of this type of construction on envelope thermal performance has been ignored by much of the design industry.

5.5 Roofs

In many cases the thermal performance of roof structures is similar to that of walls, and calculations can be performed in a similar way as described earlier. As was the case with walls, metal penetrations through the insulation will exact a penalty.

5.6 Floors

Floors above grade and exposed to outdoor air can be calculated much the same way as for walls, except that the percentages assumed for floor joists will vary somewhat from that assumed for typical wall constructions.

5.7 Fenestrations

The terms "Fenestration," "window," and "glazing" are often used interchangeably. To describe the important aspects of performance in this area requires that terms be defined carefully. "Fenestration" refers to the design and position of windows, doors and other structural openings in a building. *Glazing* is the transparent component of glass or plastic windows, doors, clerestories, or skylights. The sash is a frame in which the glass panes of a window are set. The *Frame* is the complete structural enclosure of the glazing and sash system. *Window* is the term we give to an entire assembly comprised of the sash, glazing, and frame.

Because a window is a thermally nonhomogeneous system of components with varying conductive properties, the thermal performance cannot be accurately approximated by the one-dimensional techniques used to evaluate common opaque building envelope components. The thermal performance of a window system will vary significantly, depending on the following characteristics:

- The number of panes
- The dimension of the space between the panes
- The type of gas between the panes

- The emissivity of the glass
- The frame in which the glass is installed
- The type of spacers that separate the panes of glass

5.8 Emissivity

Emissivity describes the ability of a surface to give off thermal radiation. The lower the emissivity of a warm surface, the less heat loss that it will experience due to radiation. Class performance can be substantially improved by the application of special low emissivity coatings. The resulting product has come to be known as "Low-S" glass. Two techniques for applying the Low-E film are sputter and pyrolytic coating. The lowest emittances are achieved with a sputtering process by magnetically depositing silver to the glass inside a vacuum chamber. Sputter coated surfaces must be protected within an insulated glass unit and are often called "soft coat." Pyrolytic coating is a newer method which applies tin oxide to the glass while it is still somewhat molten. The pyrolytic process results in higher emittances than sputter coating, but surfaces are more durable and can be used for single glazed windows. While normal glass has an emissivity of approximately 0.84, pyrolytic coatings can achieve emissivities of approximately 0.40 and sputter coating can achieve emissivities of 0.10 and lower. The emittance of various Low-P glasses will vary considerably between manufacturers.

5.9 Infiltration

Infiltration is the uncontrolled inward air leakage through cracks and interstices in a building element and around windows and doors of a building, caused by the effects of wind pressure and the differences in the outdoor/indoor air density. The heat loss due to infiltration is described by the following equation: qinfiltration = 0.019 x Q X (Tinside — Toutside) Where Q is the infiltration air flow in cubic feet per hour.

6.0 Heating, Ventilation and Air-Conditioning (HVAC)

6.1Introduction

The mechanical heating or cooling load in a building is dependent upon the various heat gains and losses experienced by the building including solar and internal heat gains and heat gains or losses due to transmission through the building envelope and infiltration (or ventilation) of outside air. The primary purpose of the heating, ventilating, and air-conditioning (HVAC) system in a building is to regulate the dry-bulb air temperature, humidity and air quality by adding or removing heat energy. Due to the nature of the energy forces which play upon the building and the various types of mechanical systems which can be used in non-residential buildings, there is very little relationship between the heating or cooling load and the energy consumed by the HVAC system. This chapter outlines the reasons why energy is consumed and wasted in HVAC systems for non-residential buildings. These reasons fall into a variety of categories, including energy conversion technologies, system type selection, the use or misuse of outside air, and control strategies. Following a review of the appropriate concerns to be addressed in analyzing an existing HVAC system, the chapter discusses the aspects of human thermal comfort. Succeeding sections deal with HVAC system types, energy conservation opportunities and domestic hot water systems.

6.2Surveying Existing Conditions

As we know the first stage of any effective energy management program is an energy audit of the facility in question. In surveying the HVAC system(s) in a facility, the first step is to find out what you have to work with: what equipment and control systems exist. It is usually beneficial to divide the HVAC systems into two categories: equipment and systems which provide heating and cooling, and equipment and systems which provide ventilation. It is essential to fully document the type and status of all equipment from major components including boilers, chillers, cooling towers and air-handling units to the various control systems: thermostats, valves and gauges, whether automated or manual; in order to later determine what elements can be replaced or improved to realize a saving in energy consumed by the system.

The second step is to determine how the system is operating. This requires that someone measure the operating parameters to determine whether the system actually operates as it was specified to operate. Determine the system efficiency under realistic conditions. This may be significantly different from the theoretical, or full-load efficiency. Determine how the system is operated. What are the hours of operation? Are changes in system controls manual or automatic? Find out how the system is actually operated, which may differ from how the system was designed to be operated. It is best to talk to operators and/or users of the system who know a lot more about how the system operates than the engineers or managers.

6.3 Human Thermal Comfort

The ultimate objective of any heating, cooling and ventilating system is typically to maximize human thermal comfort. Due to the prevalence of simple thermostat control systems for residential and small-scale commercial HVAC systems, it is often believed that human thermal comfort is a function solely, or at least primarily, of air temperature. But this is not the case.

Human thermal comfort is actually maximized by establishing a heat balance between the occupant and his or her environment. Since the body can exchange heat energy with its environment by conduction, convection and radiation, it is necessary to look at the factors which affect these heat transfer processes along with the body's ability to cool itself by the evaporation of perspiration.

All living creatures generate heat by burning food, a process known as metabolism. Only 20 percent of food energy is converted into useful work; the remainder must be dissipated as heat. This helps explain why we remain comfortable in an environment substantially cooler than our internal temperature of nearly 100°F (37°C). In addition to air temperature, humidity, air motion and the surface temperature of surroundings all have a significant influence on the rate at which the human body can dissipate heat. At temperatures below about 80°F (27°C) most of the body's heat loss is by convection and radiation. Convection is affected mostly by air temperature, but it is also strongly influenced by air velocity. Radiation is primarily a function of the relative

Heat transfer by conduction is negligible, since we make minimal physical contact with our surroundings which is not insulated by clothing. At temperatures above 80°F (27°C) the primary heat loss mechanism is evaporation. The rate of evaporation is dependent on the temperature and humidity of the air, as well as the velocity of air which passes over the body carrying away evaporated moisture. In addition to these environmental factors, the rate of heat loss by all means is affected by the amount of clothing, which acts as thermal insulation. Similarly, the amount of heat which must be dissipated is strongly influenced by activity level. Thus, the degree of thermal comfort achieved is a function of air temperature, humidity, air velocity, the temperature of surrounding surfaces, the level of activity, and the amount of clothing worn.

In general, when environmental conditions are cool the most important determinant of human thermal comfort is the radiant temperature of the surroundings. In fact a five degree increase in the mean-radiant temperature of the surroundings can offset a seven degree reduction in air temperature.

When conditions are warm, air velocity and humidity are most important. it is not by accident that the natural response to being too warm is to increase air motion. Similarly, a reduction in humidity will offset an increase in air temperature., although it is usually necessary to limit relative humidity to no more than 70% in summer and no less than 20% in winter.

There is, of course, a human response to air temperature, but it is severely influenced by these other factors. The most noticeable comfort response to air temperature is the reaction to drift, the change of tempera- hire over time. A temperature drift of more than one degree Fahrenheit per hour (0.5°C/hr) will result in discomfort under otherwise comfortable conditions. Temperature stratification can also cause discomfort, and temperature variation within the occupied space of a building should not be allowed to vary by more than 5 degrees F (3°C).

Modem control systems for HVAC systems can respond to more than just the air temperature. One option which has been around for a long time is the humidistat, which senses indoor humidity levels and controls humidification. However, state-of-the-art control systems can measure *operative temperature,* which is the air temperature equivalent to that affected by radiation and convection conditions of an actual environment. Another useful construct is that of effective temperature, which is a computed temperature that includes the effects of humidity and radiation. The location and type of air distribution devices play a role equal in importance to that of effective controls in achieving thermal comfort. The discomfort caused by stratification can be reduced or eliminated by proper distribution of air within the space.

7.0 Lighting

7.1 Introduction

In today's cost-competitive, market-driven economy, everyone is seeking technologies or methods to reduce energy expenses and environmental impact. Because nearly all buildings have lights, lighting initially and also retrofits are very common and generally offer an attractive return on investment. Electricity used to operate lighting systems represents a significant portion of total electricity consumed in India.

An attractive feature of lighting retrofits is they typically provide savings for both kW and kWh charges. Thus, the potential for money savings is increased. Many lighting retrofits can also improve the visual environment and worker productivity. Conversely, if a lighting retrofit reduces lighting quality, worker productivity may drop arid the energy savings could be overshadowed by reduced profits. This was the case with the lighting retrofits of the 1970s, when employees were left "in the dark" due to massive de-lamping initiatives. However, due to substantial advances in technologies, today's lighting retrofit its can reduce energy expenses while *improving* lighting quality and worker productivity.

7.2 Lighting Fundamentals

This section will introduce the important concepts about lighting, and the two objectives of the lighting designer: (1) to provide the right quantity of light, and (2) provide the right quality of light.

Lighting Quantity

Lighting quantity is the amount of light provided to a room. Unlike light quality, light quantity is easy to measure and describe.

Units

Lighting quantity is primarily expressed in three types of units: watts, lumens and foot-candles (fc). The watt is the unit for measuring electrical power. It defines the rate of energy consumption by an electrical device when it is in operation. The amount of watts consumed represents the electrical input to the lighting system. The output of a lamp is measured in lumens. For example, one standard four-foot fluorescent lamp would provide 2,990 lumens in a standard office system. The amount of lumens can also be used to describe the output of an entire fixture (comprising several lamps). Thus, the number of lumens describes how much light is being produced by the lighting system.

The number of foot-candles shows how much light is actually reaching the workplane (or task). Foot-candles are the end result of watts being converted to lumens, the lumens escaping the fixture and traveling through the air to reach the workplane. In an office, the workplane is the desk level. You can measure the amount of foot-candles with a light meter when it is placed on the work surface where tasks are performed. Foot-candle measurements are important because they express the "result" and not the "effort" of a lighting system.

Efficacy

Similar to efficiency, efficacy describes an output/ input ratio, the higher the output (while input is kept constant), the greater the efficacy. Efficacy is the amount of lumens per watt from a particular energy source. A common misconception in lighting terminology is that lamps with greater wattage provide more light. However, light sources with high efficacy can provide more light with the same amount of power (watts), when compared to light sources with low efficacy.

Lighting Quality

Lighting quality can have a dramatic influence on the attitude and performance of occupants. In fact, different "moods" can be created by a lighting system. Consider the behavior of people when they eat in different restaurants. If the restaurant is a fast-food restaurant, the space is usually illuminated by bright white lights, with a significant amount of glare from shiny tables. Occupants rarely spend much time there partly because the space creates an uncomfortable mood and the atmosphere is "fast" (eat and leave). In contrast, consider an elegant restaurant with a candle-lit tables and a "warm" atmosphere. Occupants tend to relax and take more time to eat. Although occupant behavior is also linked to interior design and other factors, lighting quality represents a significant influence. Occupants perceive and react to a space's light color. It is important that the lighting designer be able to recognize and create the subtle aspects of an environment that define the theme of the space. For example, drug and grocery stores use white lights to create a "cool" and "clean" environment. Imagine if these spaces were illuminated by the same color lights as in an elegant restaurant. How would the perception of the store change?

Occupants can be influenced to work more effectively if they are in an environment that promotes a "work-like" atmosphere. The goal of the lighting designer is to provide the appropriate quality of light for a particular task to create the right "mood" for the space.

Table 14 Recommended Light Levels for Visual Tasks

S.No.	Building Space Type	Guideline Illuminanace Range (Foot Candles)	S.No.	Building Space Type	Guideline Illuminanace Range (Foot Candles)
1	Commercial interiors		3	Industrial interiors	
	Art galleries	30-100		Ordinary tasks	50
	Banks	50-150		Stockroom storage	20
	Hotels (rooms and lobbies)	10-50		Loading and	30

				unloading	
	Offices	30-100		Difficult tasks	100
	-Average reading and writing	50-75		Highly difficult tasks	200
	-Hallways	10-20		Very difficult tasks	300-500
	-Rooms with computers	20-50		Most difficult tasks	500-10000
	Restaurants (dining areas)	20-50	4	Exterior	
	Stores (general)	20-50		Building security	1-5
	Merchandise	100-200		Floodlighting	5-30
2	Institutional interiors			Parking	1-5
	Auditoriums / assembly places	15-30			
	Hospitals (general areas)	10-15			
	Libraries	50-100			

Lighting quality can be divided into four main considerations: Uniformity, Glare, Color Rendering Index and Coordinated Color Temperature.

Uniformity

The uniformity of illuminance describes how evenly light spreads over an area. Creating uniform illumination requires proper fixture spacing. Non-uniform illuminance creates bright and dark spots, which can cause discomfort for some occupants.

Glare

Glare is a sensation caused by relatively bright objects in an occupant's field of view. The key word is *relative,* because glare is most probable when bright objects are located in front of dark environments..

Visual Comfort Probability (VCP)

The Visual Comfort Probability is a rating given to a fixture which indicates the percent of people who are comfortable with the glare. Thus, a fixture with a VCP = 80 means that 80% of occupants are comfortable with the amount of glare from that fixture. A minimum VCP of 70 is recommended for general interior spaces. Fixtures with VCPs exceeding 80 are recommended in computer areas and high-profile executive office environments.

Visual Display Terminals (VDTS)

Today's office environment contains a variety of special visual tasks, including the use of computer monitors or visual display terminals (VDTS). Occupants using VDTS are extremely vulnerable to glare and discomfort. When reflections of ceiling lights are visible on the VDT screen, the occupant has difficulty reading the screen. This phenomenon is also called "discomfort glare," and is very common in rooms that are uniformly illuminated by fixtures with low a VCP. Therefore, lighting for VDT environments must be carefully designed, so that occupants remain comfortable. because the location VOTs can be frequently changed, lighting upgrades should also be designed to be adjustable. Moveable task lights and fixtures with high **VCF** are very popular for these types of applications.

Lighting Controls

Lighting controls offer the ability for systems to be turned ON and OFF either manually or automatically. There are several control technology upgrades for lighting systems, ranging from simple (installing manual switches in proper locations) to sophisticated (installing occupancy sensors).

7.3 Process to Improve Light Efficiency

The three basic steps to improving the efficiency of lighting systems:

1. Identify necessary light quantity and quality to perform visual task.

2. Increase light source efficiency if occupancy is frequent.

3. Optimize lighting controls if occupancy is infrequent.

7.4 Maintenance

Isolated systems

Most lighting manuals prescribe specialized technologies to efficiently provide light for particular tasks. An example is dimmable ballasts. For areas that have sufficient daylight, dimmable ballasts can be used with integrated circuitry to reduce energy consumption during peak periods. Still, though there may be some shedding of lighting load along the perimeter, these energy cost savings may not represent a great percentage of the building's total lighting load. Further, applications of specialized technologies (such as dimmable ballasts) may be dispersed and isolated in several buildings, which can become a complex maintenance challenge, even if lamp types and locations are recorded properly. If maintenance personnel need to make additional site visits to get the right equipment to re-lamp or "fine-tune" special systems, the labor costs may exceed the energy cost savings.

Energy saving checklist.

Lighting needs	
Visual tasks: specification	Identify specific visual tasks and locations to determine recommended illuminances for tasks and for surrounding areas.
Safety and aesthetics	Review lighting requirements for given applications to satisfy safety and aesthetic criteria.
Over-illuminated application	In existing spaces, identify applications where maintained illumination is greater than recommended. Reduce energy by adjusting illuminance to meet recommended levels.
Groupings similar visual tasks	Group visual tasks having the same illuminance requirements, and avoid widely separated workstations
Task lighting	Illuminate work surfaces with luminaries properly located in or on furniture; provide lower ambient levels.
Luminance ratios	Use wall-washing and lighting of decorative objects to balance brightness.
Space Design and Utilization	
Space plan	When possible, arrange for occupants working after hours to work in close proximity to one another
Room surfaces	Use light colors for walls, floors, ceilings and furniture to increase utilization of Light, and reduce connected lighting power to achieve required illuminances. Avoid glossy finishes on room and work

	surfaces to limit reflected glare.
Space utilization branch circuit wiring	Use modular branch circuit wiring to allow for flexibility in moving, relocating or adding luminaries to suit changing space configurations
Space utilization occupancy	Light building for occupied periods only, and when required for security or cleaning purposes
Daylighting	
Daylight compensation	If daylighting can be used to replace some electric lighting near fenestration during substantial periods of the day, lighting in those areas should be circuited so that it may be controlled manually or automatically by switching or dimming.
Daylight sensing	Daylight sensors and dimming systems can reduce electric lighting energy.
Daylight control	Maximize the effectiveness of existing fenestration-shading controls (interior and exterior) or automatically by switching or dimming
Space utilization	Use daylighting in transition zones, in lounge and recreational areas, and for functions where the variation in color, intensity and direction may be desirable. Consider applications where daylight can be utilized as ambient lighting, supplemented by local task lights
Lighting Sources: Lamps and Ballasts	
Source efficacy	Install lamps with the highest efficacies to provide the desired light

	source color and distribution requirements
Fluorescent lamps	Use T8 fluorescent and high-wattage compact fluorescent systems for improved source efficacy and color quality.
Ballasts	Use electronic or energy efficient ballasts with fluorescent lamps.
HID	Use high-efficacy metal halide and high-pressure sodium light sources for exterior floodlighting.
Incandescent	Where incandescent **sources** are necessary, use reflector halogen lamps for increased efficacy.
Compact fluorescent	Use compact fluorescent lamps, where possible, to replace incandescent sources
Lamp wattage reduced-wattage lamps	Use reduced-wattage lamps where illuminance is too high.
Control compatibility	If a control system is used, check compatibility of lamps and ballasts with the control device.
System change	Substitute metal halide and high-pressure sodium systems for existing mercury vapor lighting systems.
Luminaires	
Maintained efficiency	Select luminaires which do not collect dirt rapidly and which can be easily cleaped.
Improved	Improved maintenance procedures may enable a lighting system with

maintenance	reduced wattage to provide adequate illumination throughout systems or component life.
Heat removal	Check luminaire effectiveness for task lighting and for overall efficiency; if ineffective or inefficient, consider replacement or relocation.
Lighting controls	
Switching, local control	Install switches for local and convenient control of lighting by occupants. This should be in combination with a building-wide system to turn lights off when the building is unoccupied.
Selective switching	Install selective switching of luminaires according to groupings of working tasks and different working hours.
Low-voltage switching systems	Use low-voltage switching systems to obtain maximum switching capability.
Master control system	Use a programmable low-voltage master switching system For the entire building to him lights on and off automatically as needed, with overrides at individual areas.
Multipurpose spaces	Install multi-circuit switching or preset dimming controls to provide flexibility when spaces are used For multiple purposes and require different ranges of illuminance for various activities. Clearly label the control cover plates.
"Tuning"	Use switching and dimming systems as a means of adjusting

illuminance	illuminance For variable lighting requirements.
Scheduling	Operate lighting according to a predetermined schedule, based on occupancy.
Occupant/motion sensors	Use occupant/motion sensors for unpredictable patterns of occupancy.
Lumen maintenance	Fluorescent dimming systems may be utilized to maintain illuminance throughout lamp life, thereby saving energy by compensating for lamp-lumen depreciation and other light loss factors.
Ballast switching	Use multilevel ballasts and local inboard-outboard lamp switching where a reduction in illuminances is sometimes desired
Operation and Maintenance	
Education	Analyze lighting used during working and building cleaning periods, and institute an education program to have personnel turn off incandescent lamps promptly when the space is not in use.
Parking	Restrict parking after hours to specific lots so lighting can be reduced to minimum security requirements in unused parking areas
Custodial service	Schedule routine building cleaning during occupied hours.
Reduced illuminance	Reduce illuminance during building cleaning periods.
Cleaning	Adjust cleaning schedules to minimize time of operation, by concentrating

schedules	cleaning activities in fewer spaces at the same time and by turning off lights in unoccupied areas.
Program evaluation	Evaluate the present lighting maintenance program, and revise it as necessary to provide the most efficient use of the lighting system.
Cleaning and maintenance	Clean luminaires and replace lamps on a regular maintenance schedule to ensure proper illuminance levels are maintained.
Regular system checks	Check to see if all components are in good working condition. Transmitting or diffusing media should be examined, and badly discolored or deteriorated media replaced to improve efficiency.
Renovation of luminaries	Replace outdated or damaged luminaires with modem ones which have good cleaning capabilities and which use lamps with higher efficacy and good lumen maintenance characteristics
Area maintenance	Trim trees and bushes that may be obstructing outdoor luminaire distribution and creating unwanted shadow.

8.0 Use of Alternative Energy

8.1 Introduction

Any energy source that is classified as an "alternative energy source" is that because, at one time it was not selected as the best choice. If the original choice of an energy source was a proper one the use of an alternative energy source would make sense only if some condition has changed. This might be:

1. Present or impending nonavailability of the present energy source

2. Change in the relative cost of the present and the alternative energy

3. Improved reliability of the alternative energy source

4. Environmental or legal considerations

To some, an alternative energy source is a nondepleting or renewable energy source, and, for many it is this characteristic that creates much of the appeal. Although the terms "alternative energy source" and "renewable energy sources" are not intended by this writer to be synonymous, it will be noted that some of the alternative energy sources discussed in this section are renewable.

It is also interesting that what we now think of as alternative energy sources, for example solar and wind, were at one time important conventional sources of energy. Conversely, natural gas, coal, and oil were, at some time in history, alternative energy sources. Changes in the four conditions listed above, primarily conditions 2 and 3, have led us full circle from the use of solar and wind, to the use of natural gas, coal, and oil, and back again in some situations to a serious consideration of solar and wind.
In a strict sense, technical feasibility is not a limitation in the use of the alternative energy sources that will be discussed. Solar energy can be collected at any reasonable temperature level, stored, and utilized in a variety of ways. Wind energy conversion systems are now functioning and have been for many years. Refuse-derived fuel has also been used for many years. What is important to one who must manage energy systems

are the factors of economics, reliability, and in some cases, the nonmonetary benefits, such as public relations.

Government funding for R&D as well as tax incentives in the alternative energy area dropped sharply during the decade of the eighties and early nineties. This caused many companies with alternative energy products to go out of business, and for others to cut back on production or to change into another product or technology line. Solar thermal energy has been hit particularly hard in this respect, but solar powered photovoltaic cells have had continued growth both in space and in terrestrial applications. Wind energy systems have continued to be installed throughout the world and show promise of continued growth. The burning of refuse has met with some environmental concerns and strict regulations. Recycling of some refuse materials such as paper and plastics has given an alternative to burning. Fuel cells continue to increase in popularity in a wide variety of applications including transportation, space vehicles, electric utilities and uninterruptible power supplies.

Surviving participants in the alternative energy business have in some cases continued to grow and to improve their products and their competitiveness. As some or all of the four conditions listed above change, we will see rising or falling interest on the part of the government, industry and private individuals in particular alternative energy systems.

8.2 Solar Energy

Availability

"Solar energy is free!" states a brochure intended to sell persons on the idea of buying their solar products. "There's no such thing as a free lunch" should come to mind at this point. With a few exceptions, one must invest capital in a solar energy system in order to reap the benefits of this alternative energy source. In addition to the cost of the initial capital investment, one is usually faced with additional periodic or random costs due to operation and maintenance. Provided that the solar system does its expected task in a reasonably reliable manner, and presuming that the conventional energy source is available and satisfactory, the important question usually is: Did it save money compared to the conventional system? Obviously, the cost of money, the cost of conventional fuel, and the cost and performance of the solar system are all important factors. As a first step in looking at the feasibility of solar energy, we will consider its availability.

Solar energy arrives at the outer edge of the earth's atmosphere at a rate of about 428 Btu/hr ft2 (1353 W/ m2). This value is referred to as the solar constant. Part of this radiation is reflected back to space, part is absorbed by the atmosphere and re-emitted, and part is scattered by atmospheric particles. As a result, only about two-thirds of the sun's energy reaches the surface of the earth. At 40° north latitude, for example, the noon time radiation rate on a flat surface normal to the sun's rays is about 300 Btu/hr. ft2 on a clear day. This would be the approximate maximum rate at which solar energy could be collected at that latitude. A solar collector tracking the sun so as to always be normal to the sun's rays could gather approximately 3.6 x 10 Btu/ft2. day as an absolute upper limit. To gather 1 million Btu/day, for example, would require about 278 ft2 (26 m2) of movable collectors, collecting all the sunlight that would strike them on a clear day.

Solar Collectors

A wide variety of devices may be used to collect solar energy. Tracking-type collectors are usually used where relatively high temperatures (above 250°F) are required.

The fraction of the incident sunlight that is collected by the solar collector for useful purposes is called the collector efficiency. This efficiency depends upon several variables, which might change for a fixed absorber plate design and fixed amount of back and side insulation. These are:

1. Rate of insolation

2. Number and type of glazing

3. Ambient air temperature

4. Average (or entering) coolant fluid temperature

Control Systems

Solar systems should operate automatically with little attention from operating personnel. A good control system will optimize the performance of the system with reliability and at a reasonable cost. The heart of any solar thermal collecting system is a device to turn on the collector fluid circulating pump (and other necessary devices) when the sun is providing sufficient insolation so that energy can be collected and stored, or used. With flat-plate collectors it is common to use a differential temperature controller , a device with two temperature sensors. One sensor is normally located on the collector fluid outlet and the other in the storage tank near the outlet to the heat exchanger (or at the level of the internal heat exchanger). When the sun is out, the fluid in the collector is heated. When a prescribed temperature difference (about 20°F) exists between the two sensors, the controller turns on the collector pump and other necessary devices. If the temperature difference drops below some other prescribed difference (about 3 to 5°F), the controller turns off the necessary devices. Thus clouds or sundown will cause the system to shut down and prevent not only the unnecessary loss of heat to the collectors but also the unnecessary use of electricity. The distinct temperature difference to start and to stop is to prevent excessive cycling.

Sizing and Economics

In almost any solar energy system the largest single expense are the solar collector panels and support structure. For this reason the system *is* usually "sized" in terms of collector panel area. Pumps, piping, heat exchangers, and storage tanks are then selected to match. Very rarely can a solar thermal system provide 100% of the energy requirements for a given application. The optimum-size solar system is the one that is the most economical on some chosen basis. The computations may be based on (1) lowest life-cycle cost, (2) quickest payout, (3) best rate of return on investment, and, (4) largest annual savings. All of these computations involve the initial installed cost, the operating and maintenance costs, the life of the equipment, the cost of money, the cost of fuel, and the fuel escalation rate, in addition to computations involving the amount of energy furnished by the solar system.

8.3 Wind Energy

Wind energy to generate electricity is most feasible at sites where wind velocities are consistently high and reasonably steady. Ideally these sites should be remote from densely populated areas, since noise generation, safety, and disruption of TV images may be problems. On the other hand the generators must be close enough to a consumer that the energy produced can be utilized without lengthy transmission.

9.0 Visual Doe: The Software Used for Modeling the Building

9.1 Significant features :

- Check Model Definitions
- Advanced Edit of Alternatives
- Polygon Clipping Module
- Water-side Economizer
- Import Schedules from DOE-2 and Energy Plus Files
- Import Cool Tools Chillers
- Diagnostics of Systems
- Water-cooled Condenser for Packaged Systems of PSZ, PVAVS and PVVT
- Ground Source Heat Pump Systems
- Re-order Design Alternatives
- LEED Style End-use Report
- Run Multiple Copies on the Same PC
- DOE-2 Manuals with Bookmarks
- New VisualDOE 4 User Manual
- Updated Online Help System

9.2 Check Model Definitions

Users can check whether a model is defined correctly before or after running simulations. If there are errors or warnings in the model, users will get alert messages identifying the sources. Then users can locate and fix the error quickly. This will catch most errors in a model and save users a significant amount of time to troubleshoot a model. The logic used to catch errors is based on our technical support for thousands of Visual DOE users worldwide.

9.3 Advanced Edit of Alternatives

Advanced edit of alternatives provides handy tools to help users model features not supported by previous versions of Visual DOE, and will save users significant amount of time in creating a large energy model with hundreds of spaces, facades, and/or systems. These advanced editing features are designed for experienced users of Visual DOE; beginners should use with caution.

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9.4 New Model Features

Rooms

• Use pre-calculated ASHRAE weighting factors by entering floor weight, furniture type, furniture fraction and furniture weight. Previous versions of VisualDOE default to custom weighting factors (with floor weight set to 0).

• Change space design temperature. The space design temperature is the constant temperature setpoint used for heating and cooling loads calculation in the LOADS module of DOE-2. The calculated peak loads are used for auto-sizing calculations of airflow and heating/cooling capacity in the SYSTEMS module of DOE-2. Previous versions of VisualDOE default to 70°F for IP units.

Facades

• Adiabatic Wall. Users can specify some exterior walls to be adiabatic (no heat transfer through these walls)

• Underground Wall. Users can specify some exterior walls to be underground walls with heat transfer modeled differently by DOE-2.

• Calculate Surface Temperature. Inside and outside surfaces temperatures can be produced in hourly reports. Hourly reports of mean radiant temperature (MRT) of a space can also be produced for further thermal comfort analysis.

• Change an exterior wall to an interior one. Based on the concept of a block, all perimeter walls of a block are assumed to be exterior walls. If a block is attached to another one, the attached walls are treated as two separate exterior walls belong to two rooms of the two blocks. To model this accurately, users can delete one of the attached walls, and change the other attached wall to be an interior one by changing the wall type to be interior and assigning the adjacent space.

• Delete exterior walls. This is mainly used for the above feature.

Zones

• Minimum Air Flow: Minimum design airflow per floor area used when DOE-2 auto-sizes zone airflow.

• Design Cooling and Heating Temperatures used in the calculation of zone airflows and heating/cooling capacity for zonal systems. These two temperatures are assigned when occupancy is selected for a space/room. Users can overwrite them without having to create another new occupancy.

• Minimum Flow Schedule. The hourly schedule of zone minimum flow ratio. Previous versions of Visual DOE assume the zone minimum flow ratio is constant for all operating hours.

• Total Cooling Capacity, Sensible Cooling Capacity, and Heating Capacity. These are inputs for zonal systems like Unit Heater, Unit Ventilator, Two Pipe Fan Coil, Four Pipe Fan Coil, Two Pipe Induction Unit, Four Pipe Induction Unit, Heat Pump, and Package Terminal Unit.

Systems

• Cooling Availability Schedule. The schedule of cooling available from the system, default to central plant cooling availability schedule.

• Heating Availability Schedule. The schedule of heating available from the system, default to central plant heating availability schedule.

5.4 Architectural Energy Corporation ©2004 Visual DOE 4.0 New Features and Enhancements

• Save systems as templates to library. Users can select some systems to save to the library so that they can be used later for new projects. All system data is saved except zones data. Users can create their own typical systems and save them to the library and share them with other engineers.

• Import system templates from library. The new Visual DOE library has more than 140 system templates for different system types, occupancies and vintages. User-saved system templates can also be imported.

• Apply a system template to selected systems. Users can apply a system template from the library to selected systems.

• Apply default system to selected systems. Users can edit the default system template and apply it to selected systems.

Objects Filtering – Rooms, Facades, and Zones

Objects filtering provide a handy way to select objects with certain criteria so that common properties can be set for these objects.

• Rooms can be filtered by their parent blocks. Users can view and edit all rooms of the model or rooms belong to a specific block. An example is a model that may have multiple blocks representing multiple buildings with different constructions and different operating schedules. Users can select rooms for a block and make changes to those rooms only.

• Facades can be filtered by orientation and their parent blocks. Users can view and edit all facades of the model or facades with a specific orientation and/or belong to a specific block. When creating an alternative for a code baseline like California Title 24 or ASHRAE 90.1, facades with common orientation will usually have common window type.

• Zones can be filtered by their parent systems. Users can view and edit zones served by a specific system.

Applying Multipliers

Users can apply multipliers to adjust lighting power density, equipment power density, and occupant density for selected rooms. For example, a user may want to decrease 20% of the lighting power for selected rooms, so he/she can enter the LPD adjustment factor of 0.8 and update the rooms.

Polygon Clipping Module

Before Visual DOE runs a simulation, all horizontal surfaces of rooms will be recreated. This is done by clipping polygons of the lower level rooms with polygons of the upper level rooms to create surfaces of roofs, ceilings, floors, and interior floors. The new polygon clipping module allows almost any complicated room shape (as long as no holes exist in the polygon), either drawn or imported from CADD DXF files. Previous versions of VisualDOE cannot handle the situation when a lower level room has more than three common horizontal surfaces with an upper level room. This new module enables users to work on more complicated models.

Architectural Energy Corporation ©2004 Visual DOE 4.0 New Features and Enhancements

Water-side Economizer

Water-side economizers are now supported. In the water-side economizer cycle, cooling towers in a central plant provide cool water instead of chilled water from chillers for space cooling.

9.5 Import Schedules from DOE-2 and EnergyPlus Files

Schedules of lighting, equipment, occupant, fan, air infiltration, cooling and heating temperature setpoints can be imported from input files for DOE-2 (created by VisualDOE, eQuest, EnergyPro, PowerDOE, or even with a text editor) and EnergyPlus. Imported schedules can be further saved to the VisualDOE library or project template files for later use or sharing among users.

Import CoolTools Chillers

The new VisualDOE library includes more than 170 electric water-cooled chillers from CoolTools database. Users can select chillers to import to the project as chiller templates. Chiller performance curves are included in the chiller template.

9.6 Diagnostics of Systems

After running a simulation, users can diagnose possible problems associated with systems like airflow, peak loads, heating and cooling capacity, and minimum outside air ratio. This is useful for verifying system sizing and to troubleshoot why there are hours some systems are not meeting loads. If heating and cooling sources are at the zone level, no heating or cooling capacity will be reported at the systems level. For example, heating (reheat) is normally done at the zone level for VAV with reheat systems, the reported heating capacity is for the central heating coil rather than the zone heating/reheat coil capacity

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Together with diagnostics of zones, users can easily discover why some zones are underheated or undercooled, or why some systems are undersized or oversized.

Water-cooled Condenser for Packaged Systems PSZ, PVAVS, and PVVT

This is a new HVAC system-modeling feature. Water-cooled condensers with cooling towers are implemented for packaged systems of PSZ (Packaged Single Zone), PVAVS (Packaged Variable Air Volume), and PVVT (Packaged Variable Volume and Variable Temperature). Water-side economizers are implemented for PSZ and PVAVS systems, which allows the condenser water to be diverted through a WSE coil (that cools the entering air) to precool the mixing air if the water temperature is more than a predetermined number of degrees below the air temperature. After leaving the WSE coil, the water then enters the unit condenser.

Water-loop heat pump (WLHP) systems cannot coexist with packaged systems (PSZ, PVAVS, and PVVT) with water-cooled condensers. This is a DOE-2 limitation.

Ground Source Heat Pump systems

This is a new HVAC system-modeling feature. To model a ground source heat pump (GSHP) system, users first create a water-loop heat pump system, then specify the option of using ground source heat pump and define properties of circulation pump. The GSHP water loop cannot have cooling tower or boiler.

9.7 LEED Style End-use Report

A new LEED style end-use report is provided so that users can copy and paste end-use and cost data to compile the submittal for the LEED Energy and Atmosphere Credit 1 – Optimal Energy Performance.

9.8 Run Multiple Copies on the Same PC

Users can run more than one copy of VisualDOE 4.0 on the same PC. The more copies you run, the more computer memory is required, which may slow down simulation runs. This is good for visually comparing two alternatives to identify differences in user inputs. It is a violation of the copyright held by Architectural Energy Corporation if users purchase a single-user license of VisualDOE but run it on multiple computers simultaneously.

9.9 DOE-2 Manuals with Bookmarks

Bookmarks are added to the DOE-2 manuals: 2.1E Supplement, BDL Summary, and 2.1A Reference Manual Part 1 for easy browsing.

New User Manual

The User Manual is updated with new contents (more than 120 new pages!) to cover features added to VisualDOE versions 3.1 and 4.0. New chapters and appendices are added to provide useful resources for performing building energy simulations. The User Manual should be the first stop if users have questions regarding VisualDOE. The tutorial is revised and new users are strongly recommended to start there.

9.10 Updated Online Help

The online help system is updated for VisualDOE 4.0.

Enhancements of VisualDOE 4.0

VisualDOE 4.0 incorporates many improvements over previous versions. The program now runs faster and is very stable. Major new improvements include:

- Custom Block Editor
- Use Smart HVAC Defaults
- Create Plenum Zones
- Water Loop Heat Pump
- VisualDOE Reports
- Move Blocks
- Description Property for Organizer Items
- Launch Schedules Organizer from the Occupancy Editor

• Updated Library and Templates

• Bug Fixes of 3.1 after October 2003

9.11 Custom Block Editor

When a room is drawn or imported from polygons in a DXF file, duplicate vertices or vertices too close to each other will be removed so that the room can be merged into the block. This version enables one decimal digit of coordinates of vertices when creating a room using (X,Y) method or editing room polygons. The maximum number of vertices for a block is expanded from 100 to 200, which enables creating complicated blocks from DXF files.

Architectural Energy Corporation ©2004 VisualDOE 4.0 New Features and Enhancements

Use Smart HVAC Defaults

When system assignments are first specified for a new project, HVAC systems will be created based on the occupancy type, floor area, and building era.

Create Plenum Zones

Only one plenum zone will be created for a system if any block served by the system has plenum. Blocks served by a same system can either have plenum or not. Previous versions of VisualDOE may create two plenum zones if one block served by the system is on the top level of the building while another block is at lower level. Previous versions of VisualDOE may produce an error by creating a plenum zone with zero air volume if some blocks served by a HVAC system have plenum zones while others do not.

Water Loop Heat Pump

The Water Loop Heat Pump editor has added new inputs (maximum and minimum supply air temperatures at zones, loop water flow rate, loop operating temperature setpoints) and consolidated existing inputs, which provides user more control of a WLHP system operation.

VisualDOE Reports

VisualDOE reports including Architectural Summary, Zone Summary, System Summary, and Plant Summary are updated with new useful information.

Move Blocks

A standard block or custom block can be moved by changing the X and/or Y of the block at the Blocks tab of the VisualDOE interface. Another way to move a block is by using the Custom Block Editor, but this may require zones to be recreated and zones data lost.

Description Property for Organizer Items

A new property description is added to Organizer items such as materials, constructions, glazings, openings, schedules, and occupancies.

Launch Schedules Organizer from the Occupancy Editor

When working on the Occupancy Editor, users can launch the Schedules Organizer directly to create a new schedule.

Library and Templates

Library and project templates have been updated. 20 new occupancies and their schedules have been added to the library. Lighting and equipment schedules for energy simulation and load calculation for small, medium and large office buildings from ASHRAE Research Project 1093 are also added to the library.

WINDOW WALL RATIO (WWR) = 45%

TERI	**HEAT LOAD CALCULATION**				LOWER GROUND FLOOR BASE CASE		
NEW DELHI					~~~~~~~~~~~~~~~~~~		
~~				Flr.Tem.	1,2,3	2	10
Place		IIT Roorkee			Outside	Space	Diff
Bldg Name		Central Library			~~~~~~~ ~~~~~~~	~~~~	~~~~
Name of area:		Ground Floor		Deg FDB	110	75	35
Prepared by:		Firoz		Deg FWB	75	63	12.5
Date:		June 14 2008		Gr/Lb	74	64	10
File Name		Lower GF		Th.	38.5	28	10.4
Height(ft)	**12**			Roof Temp	1,2,3	0	1
Wall Thickness	9	1	0.337	Roof ins.	0,1,2,3	0	0.41
Floor	24739			A.C :	1	4948	
Floor 1,2	2	0.41		CFM/pers.	15	1350	4947.8
Wall	***L(ft.)***	***H(ft.)***	***Area(sft)***	***Nett(sft)***	***Factor***	***T.D.***	***Btu/Hr***
SPACE SENSIBLE LOAD							
N Wall	**160**	**12**	1920	1560	0.337	35	18400
Glass	**120**	**3**	360				
S Wall	**160**	**12**	1920	1560	0.337	35	18400
Glass	**120**	**3**	360				
E Wall	**160**	**12**	1920	1560	0.337	35	18400
Glass	**120**	**3**	360				
W Wall	**160**	**12**	1920	1560	0.337	50	26286
Glass	**120**	**3**	360				

NE Wall		0	12	0	0	0.337	35	0
Glass		0	0	0				
NW Wall		0	12	0	0	0.337	45	0
Glass		0	0	0				
SE Wall		0	12	0	0	0.337	35	0
Glass		0	0	0				
SW Wall		0	12	0	0	0.337	45	0
Glass		0	0	0				
Floor		24739	1	24739	24739	0.41	10	101430
Roof		A.C :		0	0	0.41	1	0
Partition		0	12	0	0	0.337	25	0
Ceiling		0	0	0	0	0.337	25	0
Sunglass	(N,S,E,NE,SE)				1080	**0.71**	12	9202
Sunglass	(W)				360	**0.71**	160	40896
Sunglass	(NW,SW)				0	**0.71**	120	0
All Glass					1440	**1.087**	35	54785
Lights		1	13000		13000	1.2	3.4	53196
Equipment		1	5000		5000	1	3.4	17050
People		90				1	230	20700
Ventilation				4947.8	0.1	1.08	35	18703
				Space Sensible Heat				397448
				Duct Heat Gain + Fan H.P. + Safety Factor (15%)				59617
				Total Space Sensible Heat				457065

Job No.	IIT Roorkee	Area :	Ground Floor	By :	Firoz	Date :	June 14 2008

SPACE LATENT LOAD

Ventilation				4947.8	0.1	0.67	10	3315
People		90				1	220	19800

		Space Latent Heat				23115
		Safety Factor 10%				2312
		Total Space Latent Heat				25427
		Total Space Sensible Heat				457065
		Total Space Heat				482492
VENTILATION AIR HEAT						
Ventilation	4947.8	0.9		4.5	10	208401
		Refrigeration Sub Total				690893
		Return Heat Gain + Pump H.P. ++ Piping Gain (5%)				34545
		Refrigeration Total				725438
		TONS				**60.45**

APPARATUS DEW POINT

Sensible Heat Ratio	**0.95**
ADP	54.45
CFM	22882

CHECK FIGURES

SFT/TON	409		
CFM/TON	379		
CFM/SFT	0.92	SHR	ADP

					LOWER GROUND FLOOR		
TERI NEW DELHI	HEAT LOAD CALCULATION				ECBC COMPLIANT		
~~				Flr.Tem.	1,2,3	2	10
Place		IIT Roorkee			Outside	Space	Diff
Bldg Name		Central Library			~~~~~~	~~~~	~~~
Name of area:		Lower GF ECBC		Deg FDB	110	75	35
Prepared by:		Firoz		Deg FWB	75	62.5	12.5
Date:		June 14 2008		Gr/Lb	74	64	10
File Name		Lower GF		Th.	38.5	28.1	10.4
Height(ft)	12			Roof Temp	1,2,3	0	1
Wall Thickmess	9	1	0.062	Roof ins.	0,1,2,3	0	0.41
Floor	24739			A.C :	1	4948	
Floor 1,2	2	0.41		CFM/pers.	15	1350	4947.8

Wall	*L(ft.)*	*H(ft.)*	*Area(sft)*	*Nett(sft)*	*Factor*	*T.D.*	*Btu/Hr*
SPACE SENSIBLE LOAD							
N Wall	**160**	**12**	1920	1560	0.062	35	3385
Glass	**120**	**3**	360				
S Wall	**160**	**12**	1920	1560	0.062	35	3385
Glass	**120**	**3**	360				
E Wall	**160**	**12**	1920	1560	0.062	35	3385
Glass	**120**	**3**	360				
W Wall	**160**	**12**	1920	1560	0.062	50	4836
Glass	**120**	**3**	360				

NE Wall	0	12	0	0	0.062	35	0
Glass	0	0	0				
NW Wall	0	12	0	0	0.062	45	0
Glass	0	0	0				
SE Wall	0	12	0	0	0.062	35	0
Glass	0	0	0				
SW Wall	0	12	0	0	0.062	45	0
Glass	0	0	0				
Floor	24739	1	24739	24739	0.41	10	101430
Roof	A.C :		0	0	0.41	1	0
Partition	0	12	0	0	0.062	25	0
Ceiling	0	0	0	0	0.062	25	0
Sunglass	(N,S,E,NE,SE)			1080	**0.24**	12	3110
Sunglass	(W)			360	**0.24**	160	13824
Sunglass	(NW,SW)			0	**0.24**	120	0
All Glass				1440	**0.56**	35	28224
Lights	1	13000		13000	1.2	3.41	53196
Equipment	1	5000		5000	1	3.41	17050
People	90				1	230	20700
Ventilation			4947.8	0.1	1.08	35	18703
			Space Sensible Heat				271228
	Duct Heat Gain + Fan H.P. + Safety Factor (15%)		an H.P. +	Safety Factor (15%)			40684
			Total Space Sensible Heat				311912

Job No.	IIT Roorkee	Area :	Lower GF ECBC	By :	Firoz	Date :	June 14 2008

SPACE LATENT LOAD

Ventilation			4947.8	0.1	0.67	10	3315

People	90				1	220	19800
				Space Latent Heat			23115
				Safety Factor 10%			2312
			Total	al Space Latent Heat			25427
			Total Spa	Space Sensible Heat			311912
				Total Space Heat			337339
VENTILATION AIR HEAT							
Ventilation			4947.8	0.9	4.5	10.4	208401
			Refrigeration	rigeration Sub Total			545740
Return He	at Gain +		Pump H.P. +	+ Piping Gain (5%)			27287
				Refrigeration Total			573027
				TONS			**47.75**
APPARATUS DEW POINT							
Sensible Heat Ratio				**0.92**			
ADP				54			
CFM				15281			
CHECK FIGURES							
SFT/TON	518						
CFM/TON	320						
CFM/SFT	0.62			SHR	ADP		

TERI		HEAT LOAD CALCULATION				GROUND FLOOR BASE CASE	
NEW DELHI					~~~~~~~~~~~~~~~~~~~~~~		
~~				Flr.Tem.	1,2,3	2	10
Place		IIT Roorkee			Outside	Space	Diff
Bldg Name		Central Library			~~~~~~~~ ~~~~~~~~	~~~~~~	~~~~~
Name of area:		ground Floor		Deg FDB	110	75	35
Prepared by:		Firoz		Deg FWB	75	62.5	12.5
Date:				Gr/Lb	74	64	10
File Name				Th.	38.5	28.1	10.4
Height (ft)	**12**			Roof Temp	1,2,3	3	60
Wall Th.	9	1	**0.337**	Roof ins.	0,1,2,3	0	**0.41**
Floor	24739			A.C :	1	4947.8	
flr 1,2	1	0.38		CFM/pers.	15	3600	4947.8
Wall	***L(ft.)***	***H(ft.)***	***Area(sft)***	***Nett(sft)***	***Factor***	***T.D.***	***Btu/Hr***
SPACE SENSIBLE LOAD							
N Wall	**160**	**12**	1920	720	0.337	35	8492
Glass	**120**	**10**	1200				
S Wall	**160**	**12**	1920	720	0.337	35	8492
Glass	**120**	**10**	1200				
E Wall	**160**	**12**	1920	720	0.337	35	8492
Glass	**120**	**10**	1200				

W Wall	160	12	1920	720	0.337	50	12132
Glass	120	10	1200				
NE Wall	0	12	0	0	0.337	35	0
Glass	0	0	0				
NW Wall	0	12	0	0	0.337	45	0
Glass	0	0	0				
SE Wall	0	12	0	0	0.337	35	0
Glass	0	0	0				
SW Wall	0	12	0	0	0.337	45	0
Glass	0	0	0				
Floor	A.C :	1	0	0	0.38	10	0
Roof	AC	1	0	0	0.41	60	0
Partition	0	12	0	0	0.337	25	0
Ceiling			0	0	0.337	25	0
Sunglass	(N,S,E,NE,SE)			3600	0.71	12	30672
Sunglass	(W)			1200	0.71	160	136320
Sunglass	(NW,SW)			0	0.71	120	0
All Glass				4800	1.087	35	182616
Lights	1	21000		24739	1.2	3.41	101232
Equipment	1	6000		6000	1	3.41	20460
People	240				1	230	55200
Venti.			4947.8	0.1	1.08	35	18703
			Space Sensible Heat				582811
			Duct Heat Gain + Fan H.P. + Safety Factor (15%)				87422
			Total Space Sensible Heat				670233

Job No.	IIT Roorkee	Area :	ground Floor	By :	Firoz	Date :	0

SPACE LATENT LOAD

Venti.		4947.8	0.1	0.67	10	3315
People	240			1	220	52800
			Space Latent Heat			56115
			Safety Factor 10%			5612
		Total	al Space Latent Heat			61727
			Total Space Heat			731960
VENTILATION AIR HEAT						
Venti.		4947.8	0.9	4.5	10.4	208401
			Refrigeration Sub Total			940361
		Return Heat Gain + Pump H.P. + Piping Gain (5%)				47018
			Refrigeration Total			987379
			************************			**********
			TONS			82.28

APPARATUS DEW POINT		
Sensible Heat Ratio		0.92
ADP		54
CFM		32835
CHECK FIGURES		
SFT/TON	301	
CFM/TON	399	
CFM/SFT	1.33	

TERI	HEAT LOAD CALCULATION			GROUND FLOOR ECBC COMPLIANT			
NEW DELHI							
~~				~~~~~~~~~~			
			Flr.Tem.	1,2,3		2	10
Place	IIT Roorkee			Outside		Space	Diff
Bldg Name	Central Library			~~~~~		~~~	~~~
Name of area:	ground Floor		Deg FDB		110	75	35
Prepared by:	Firoz		Deg FWB		75	62.5	12.5
Date:			Gr/Lb		74	64	10
File Name			Th.		38.5	28.1	10.4
Height (ft)	12		Roof Temp	1,2,3		3	60
Wall Th.	9	1	0.062	Roof ins.	0,1,2,3	0	0.41
Floor	24739		A.C :		1	4947.8	
flr 1,2	1	0.38	CFM/pers.		15	3600	4947.8

Wall	*L(ft.)*	*H(ft.)*	*Area(sft)*	*Nett(sft)*	*Factor*	*T.D.*	*Btu/Hr*
SPACE SENSIBLE LOAD							
N Wall	160	12	1920	720	0.062	35	1562
Glass	120	10	1200				
S Wall	160	12	1920	720	0.062	35	1562
Glass	120	10	1200				
E Wall	160	12	1920	720	0.062	35	1562
Glass	120	10	1200				

W Wall		**160**	**12**	1920	720	0.062	50	2232
Glass		**120**	**10**	1200				
NE Wall		0	12	0	0	0.062	35	0
Glass		0	0	0				
NW Wall		0	12	0	0	0.062	45	0
Glass		0	0	0				
SE Wall		0	12	0	0	0.062	35	0
Glass		0	0	0				
SW Wall		0	12	0	0	0.062	45	0
Glass		0	0	0				
Floor		A.C :	1	0	0	0.38	10	0
Roof		AC	1	0	0	0.41	60	0
Partition		0	12	0	0	0.062	25	0
Ceiling				0	0	0.062	25	0
Sunglass	(N,S,E,NE,SE)				3600	**0.24**	12	10368
Sunglass	(W)				1200	**0.24**	160	46080
Sunglass	(NW,SW)				0	**0.24**	120	0
All Glass					4800	**0.56**	35	94080
Lights		1	21000		24739	1.2	3.41	101232
Equipment		1	6000		6000	1	3.41	20460
People		240				1	230	55200
Venti.				4947.8	0.1	1.08	35	18703
				Space Sensible Heat				353041
				Duct Heat Gain + Fan H.P. + Safety Factor (15%)				52956
				Total Space Sensible Heat				405997

Job No. IIT Roorkee Area : ground Floor By : Firoz Date : 0

SPACE LATENT LOAD

Venti.		4947.8	0.1	0.67	10	3315
People	240			1	220	52800
			Space Latent Heat			56115
			Safety Factor 10%			5612
		Total	al Space Latent Heat			61727
		Total Spa	Space Sensible Heat			405997
			Total Space Heat			467724
VENTILATION AIR HEAT						
Venti.		4947.8	0.9	4.5	10.4	208401
			Refrigeration Sub Total			676125
		Return Heat Gain + Pump H.P. + + Piping Gain (5%)				33806
			Refrigeration Total			709931
			TONS			59.16
APPARATUS DEW POINT						
Sensible Heat Ratio			0.87			
ADP			52.75			
CFM			18773			
CHECK FIGURES						
SFT/TON	418					
CFM/TON	317					
CFM/SFT	0.76					

TERI		HEAT LOAD CALCULATION				FIRST FLOOR BASE CASE	
NEW DELHI					~~~~~~~~~~~~~~		
~~				Flr.Tem.	1,2,3	2	10
Place		IIT Roorkee			Outside	Space	Diff
Bldg Name		Central Library			~~~~~~ ~~~~~~	~~~~	~~~
Name of area:		First Floor		Deg FDB	110	75	35
Prepared by:		Firoz		Deg FWB	75	62.5	12.5
Date:				Gr/Lb	74	64	10
File Name				Th.	38.5	28.1	10.4
Height (ft)	12			Roof Temp	1,2,3	3	60
Wall Th.	9	1	0.337	Roof ins.	0,1,2,3	0	**0.41**
Floor	21724			A.C :	1	4344.8	
flr 1,2	1	0.38		CFM/pers.	15	2250	4344.8

Wall	***L(ft.)***	***H(ft.)***	***Area(sft)***	***Nett(sft)***	***Factor***	***T.D.***	***Btu/Hr***
SPACE SENSIBLE LOAD							
N Wall	**160**	**12**	1920	720	0.337	35	8492
Glass	**120**	**10**	1200				
S Wall	**160**	**12**	1920	720	0.337	35	8492
Glass	**120**	**10**	1200				
E Wall	**160**	**12**	1920	720	0.337	35	8492
Glass	**120**	**10**	1200				

W Wall	160	12	1920	720	0.337	50	12132
Glass	120	10	1200				
NE Wall	0	12	0	0	0.337	35	0
Glass	0	0	0				
NW Wall	0	12	0	0	0.337	45	0
Glass	0	0	0				
SE Wall	0	12	0	0	0.337	35	0
Glass	0	0	0				
SW Wall	0	12	0	0	0.337	45	0
Glass	0	0	0				
Floor	A.C :	1	0	0	0.38	10	0
Roof	AC	1	0	0	0.41	60	0
Partition	0	12	0	0	0.337	25	0
Ceiling			0	0	0.337	25	0
Sunglass	(N,S,E,NE,SE)			3600	0.71	12	30672
Sunglass	(W)			1200	0.71	160	136320
Sunglass	(NW,SW)			0	0.71	120	0
All Glass				4800	1.087	35	182616
Lights	1	17000		21724	1.2	3.41	88895
Equipment	1	3000		3000	1	3.41	10230
People	150				1	230	34500
Venti.			4344.8	0.1	1.08	35	16423
			Space Sensible Heat				537264
			Duct Heat Gain + Fan H.P. + Safety Factor (15%)				80590
			Total Space Sensible Heat				617854

Job No. IIT Roorkee Area : First Floor By : Firoz Date : 0

SPACE LATENT LOAD

Venti.		4344.8	0.1	0.67	10	2911
People	150			1	220	33000
			Space Latent Heat			35911
			Safety Factor 10%			3591
		Total	al Space Latent Heat			39502
		Total Spa	Space Sensible Heat			617854
			Total Space Heat			657356

VENTILATION AIR HEAT

Venti.		4344.8	0.9	4.5	10.4	183003
		Return Heat Gain + Refrigeration Sub Total				840359
			Pump H.P. + + Piping Gain (5%)			42018
			Refrigeration Total			882377
			TONS			73.53

APPARATUS DEW POINT

Sensible Heat Ratio	0.94
ADP	54.3
CFM	30708

CHECK FIGURES

————	295
SFT/TON	418
CFM/TON	1.41
CFM/SFT	1.41

TERI	HEAT LOAD CALCULATION				FIRST FLOOR ECBC COMPLIANT		
NEW DELHI					~~~~~~~~~~~~~~~~~~~~~~~		
~~				Flr.Tem.	1,2,3	2	10
Place	IIT Roorkee				Outside	Space	Diff
Bldg Name	Central Library				~~~~~~~~~ ~~~~~~~~~	~~~~~~	~~~~~
Name of area:	First Floor			Deg FDB	110	75	35
Prepared by:	Firoz			Deg FWB	75	62.5	12.5
Date:				Gr/Lb	74	64	10
File Name				Th.	38.5	28.1	10.4
Height (ft)	12			Roof Temp	1,2,3	3	60
Wall Th.	9	1	0.062	Roof ins.	0,1,2,3	0	0.41
Floor	21724			A.C :	1	4344.8	
flr 1,2	1	0.38		CFM/pers.	15	2250	4344.8

Wall	*L(ft.)*	*H(ft.)*	*Area(sft)*	*Nett(sft)*	*Factor*	*T.D.*	*Btu/Hr*
SPACE SENSIBLE LOAD							
N Wall	160	12	1920	720	0.062	35	1562
Glass	120	10	1200				
S Wall	160	12	1920	720	0.062	35	1562
Glass	120	10	1200				
E Wall	160	12	1920	720	0.062	35	1562
Glass	120	10	1200				

W Wall		160	12	1920	720	0.062	50	2232
Glass		120	10	1200				
NE Wall		0	12	0	0	0.062	35	0
Glass		0	0	0				
NW Wall		0	12	0	0	0.062	45	0
Glass		0	0	0				
SE Wall		0	12	0	0	0.062	35	0
Glass		0	0	0				
SW Wall		0	12	0	0	0.062	45	0
Glass		0	0	0				
Floor		A.C :	1	0	0	0.38	10	0
Roof		AC	1	0	0	0.41	60	0
Partition		0	12	0	0	0.062	25	0
Ceiling				0	0	0.062	25	0
Sunglass	(N,S,E,NE,SE)				3600	0.24	12	10368
Sunglass	(W)				1200	0.24	160	46080
Sunglass	(NW,SW)				0	0.24	120	0
All Glass					4800	0.56	35	94080
Lights		1	17000		21724	1.2	3.41	88895
Equipment		1	3000		3000	1	3.41	10230
People		150				1	230	34500
Venti.				4344.8	0.1	1.08	35	16423

Space Sensible Heat 307494

Duct Heat Gain + Fan H.P. + Safety Factor (15%) 46124

Total Space Sensible Heat 353618

Job No. IIT Roorkee Area : First Floor By : Firoz Date : 0

SPACE LATENT LOAD

Venti.			4344.8	0.1	0.67	10	2911
People	150				1	220	33000
				Space Latent Heat			35911
				Safety Factor 10%			3591
			Total	al Space Latent Heat			39502
			Total Spa	Space Sensible Heat			353618
				Total Space Heat			393120
VENTILATION AIR HEAT							
Venti.			4344.8	0.9	4.5	10.4	183003
				Refrigeration Sub Total			576123
			Return Heat Gain + Pump H.P. + Piping Gain (5%)				28806
				Refrigeration Total			604929
				TONS			50.41
APPARATUS DEW POINT							
Sensible Heat Ratio				0.9			
ADP				53.5			
CFM				16921			
CHECK FIGURES							
SFT/TON	431						
CFM/TON	336						
CFM/SFT	0.78						

TERI	HEAT LOAD CALCULATION				SECOND FLOOR BASE CASE		
NEW DELHI					~~~~~~~~~~~~~~~~~~~~~~		
~~				Flr.Tem.	1,2,3	2	10
Place		IIT Roorkee			Outside	Space	Diff
Bldg Name		Central Library			~~~~~~~~ ~~~~~~~~	~~~~~~	~~~~~
Name of area:		Second Floor		Deg FDB	110	75	35
Prepared by:		Firoz		Deg FWB	75	62.5	12.5
Date:				Gr/Lb	74	64	10
File Name				Th.	38.5	28.1	10.4
Height (ft)	12			Roof Temp	1,2,3	3	60
Wall Th.	9	1	0.337	Roof ins.	0,1,2,3	0	0.41
Floor	17302			A.C :	1	3460.4	
flr 1,2	1	0.38		CFM/pers.	15	1500	3460.4

Wall	*L(ft.)*	*H(ft.)*	*Area(sft)*	*Nett(sft)*	*Factor*	*T.D.*	*Btu/Hr*
SPACE SENSIBLE LOAD							
N Wall	160	12	1920	1200	0.337	35	14154
Glass	120	6	720				
S Wall	160	12	1920	1200	0.337	35	14154
Glass	120	6	720				
E Wall	160	12	1920	1200	0.337	35	14154
Glass	120	6	720				

W Wall	**160**	**12**	1920	1200	0.337	50	20220
Glass	**120**	**6**	720				
NE Wall	0	12	0	0	0.337	35	0
Glass	0	0	0				
NW Wall	0	12	0	0	0.337	45	0
Glass	0	0	0				
SE Wall	0	12	0	0	0.337	35	0
Glass	0	0	0				
SW Wall	0	12	0	0	0.337	45	0
Glass	0	0	0				
Floor	A.C :	1	0	0	0.38	10	0
Roof	17302	1	17302	17302	0.41	60	425629
Partition	0	12	0	0	0.337	25	0
Ceiling			0	0	0.337	25	0
Sunglass	(N,S,E,NE,SE)			2160	0.71	12	18403
Sunglass	(W)			720	0.71	160	81792
Sunglass	(NW,SW)			0	0.71	120	0
All Glass				2880	1.087	35	109570
Lights	1	12000		17302	1.2	3.41	70800
Equipment	1	1000		1000	1	3.41	3410
People	100				1	230	23000
Venti.			3460.4	0.1	1.08	35	13080
			Space Sensible Heat				808366
			Duct Heat Gain + Fan H.P. + Safety Factor (15%)				121255
			Total Space Sensible Heat				929621

Job No.	IIT Roorkee	Area :	Second Floor	By :	Firoz	Date :	0

SPACE LATENT LOAD

Venti.		3460.4	0.1	0.67	10	2318
People	100			1	220	22000
			Space Latent Heat			24318
			Safety Factor 10%			2432
			Total Space Latent Heat			26750
			Total Space Sensible Heat			929621
			Total Space Heat			956371

VENTILATION AIR HEAT

Venti.		3460.4	0.9	4.5	10.4	145752
			Refrigeration Sub Total			1102123
		Return Heat Gain + Pump H.P. + Piping Gain (5%)				55106
			Refrigeration Total			1157229
			TONS			96.44

APPARATUS DEW POINT

Sensible Heat Ratio	0.97
ADP	54.75
CFM	47230

CHECK FIGURES

SFT/TON	179
CFM/TON	490
CFM/SFT	2.73

TERI	HEAT LOAD CALCULATION				SECOND FLOOR ECBC COMPLIANT		
NEW DELHI					~~~~~~~~~~~~~~~~~~~~		
~~				Flr.Tem.	1,2,3	2	10
Place	IIT Roorkee				Outside	Space	Diff
Bldg Name	Central Library				~~~~~~ ~~~~~~	~~~~~	~~~~
Name of area:	Second Floor			Deg FDB	110	75	35
Prepared by:	Firoz			Deg FWB	75	62.5	12.5
Date:				Gr/Lb	74	64	10
File Name				Th.	38.5	28.1	10.4
Height (ft)	**12**			Roof Temp	1,2,3	3	60
Wall Th.	9	1	**0.062**	Roof ins.	0,1,2,3	0	**0.072**
Floor	17302			A.C :	1	3460.4	
flr 1,2	1	0.38		CFM/pers.	15	1500	3460.4

Wall	***L(ft.)***	***H(ft.)***	***Area(sft)***	***Nett(sft)***	***Factor***	***T.D.***	***Btu/Hr***
SPACE SENSIBLE LOAD							
N Wall	**160**	**12**	1920	1200	0.062	35	2604
Glass	**120**	**6**	720				
S Wall	**160**	**12**	1920	1200	0.062	35	2604
Glass	**120**	**6**	720				
E Wall	**160**	**12**	1920	1200	0.062	35	2604
Glass	**120**	**6**	720				
W Wall	**160**	**12**	1920	1200	0.062	50	3720

Glass	**120**	**6**	720				
NE Wall	0	12	0	0	0.062	35	0
Glass	0	0	0				
NW Wall	0	12	0	0	0.062	45	0
Glass	0	0	0				
SE Wall	0	12	0	0	0.062	35	0
Glass	0	0	0				
SW Wall	0	12	0	0	0.062	45	0
Glass	0	0	0				
Floor	A.C :	1	0	0	0.38	10	0
Roof	17302	1	17302	17302	0.072	60	74745
Partition	0	12	0	0	0.062	25	0
Ceiling			0	0	0.062	25	0
Sunglass	(N,S,E,NE,SE)			2160	0.24	12	6221
Sunglass	(W)			720	0.24	160	27648
Sunglass	(NW,SW)			0	0.24	120	0
All Glass				2880	0.56	35	56448
Lights	1	12000		17302	1.2	3.41	70800
Equipment	1	1000		1000	1	3.41	3410
People	100				1	230	23000
Venti.			3460.4	0.1	1.08	35	13080
			Space Sensible Heat				286884
			Duct Heat Gain + Fan H.P. + Safety Factor (15%)				43033
			Total Space Sensible Heat				329917

Job No.	IIT Roorkee	Area :	Second Floor	By :	Firoz	Date :	0

SPACE LATENT LOAD

Venti.		3460.4	0.1	0.67	10	2318
People	100			1	220	22000
			Space Latent Heat			24318
			Safety Factor 10%			2432
		Total	al Space Latent Heat			26750
		Total Spa	Space Sensible Heat			329917
			Total Space Heat			356667

VENTILATION AIR HEAT

Venti.		3460.4	0.9	4.5	10.4	145752
			Refrigeration Sub Total			502419
		Return Heat Gain + Pump H.P. ++ Piping Gain (5%)				25121
			Refrigeration Total			527540
			TONS			43.96

APPARATUS DEW POINT

Sensible Heat Ratio	0.93
ADP	54.15
CFM	16279

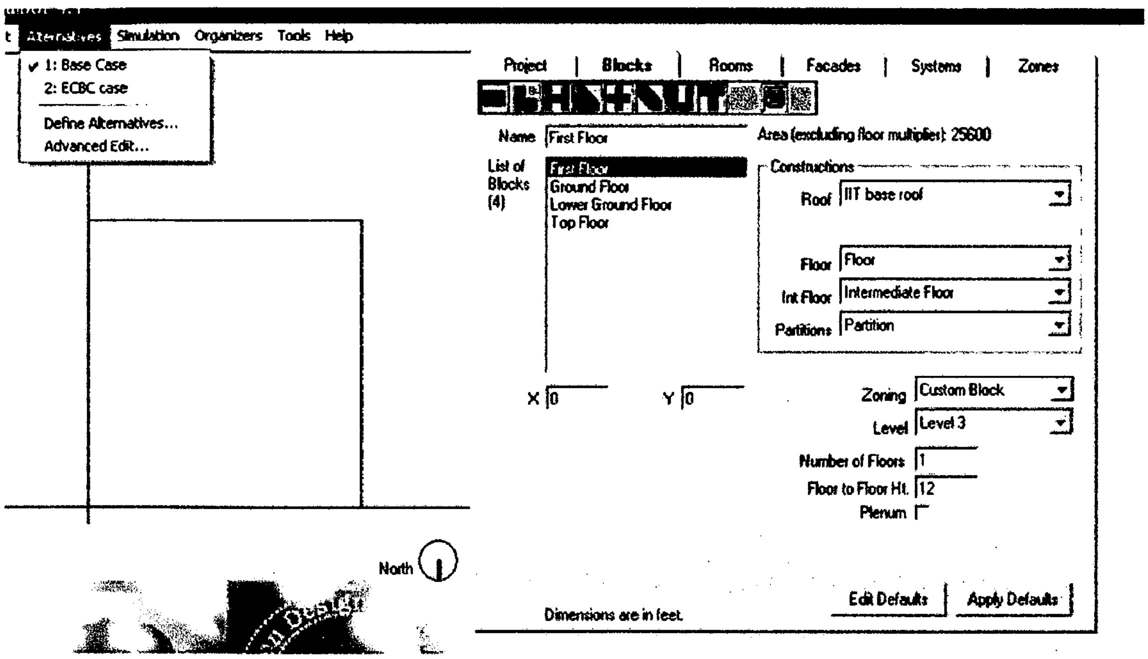
CHECK FIGURES

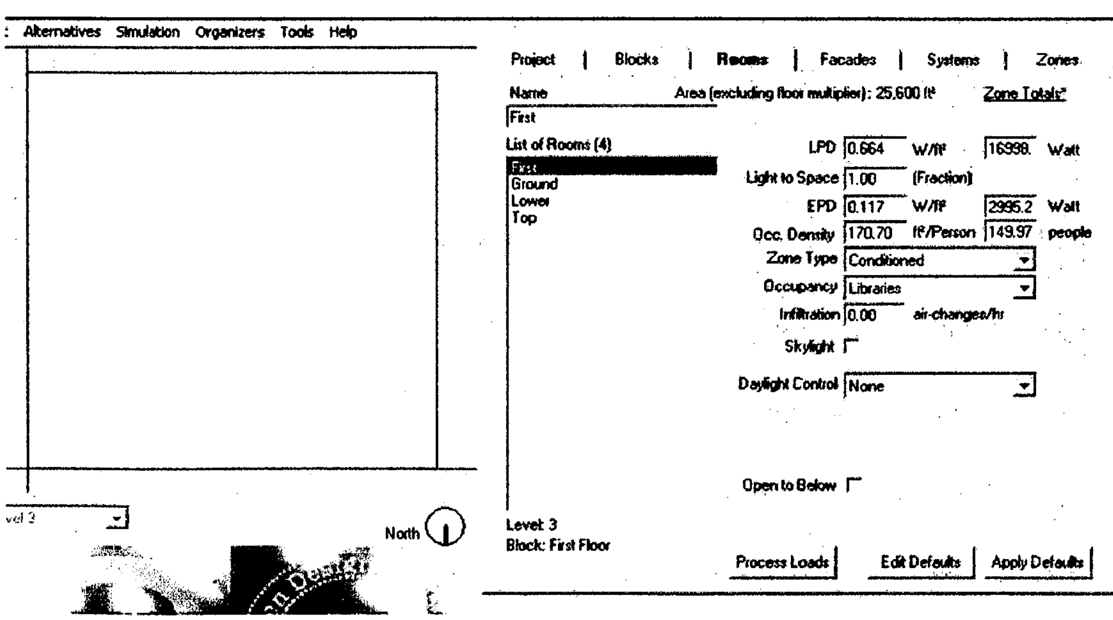
SFT/TON	394
CFM/TON	370
CFM/SFT	0.94

ENERGY PERFORMANCE REPORT

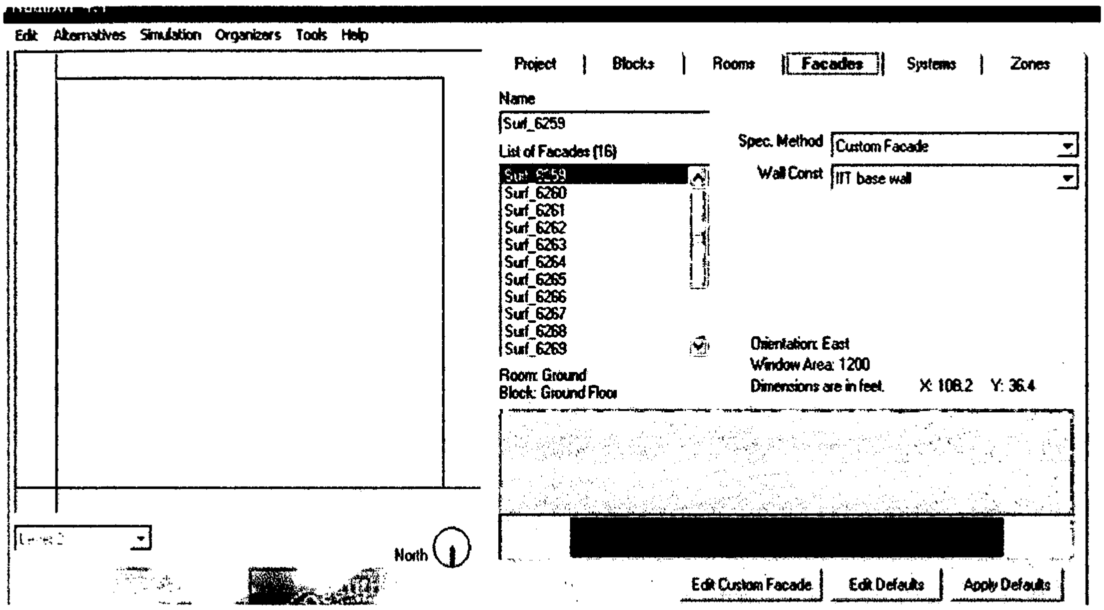
ELECTRICAL USE SUMMARY

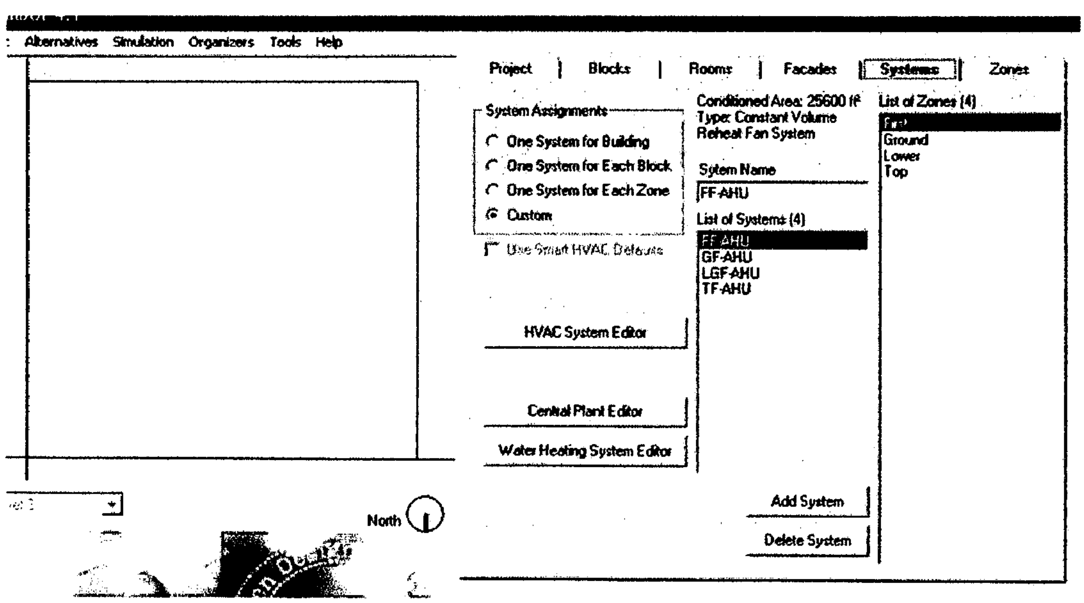
Alternative	Lights	Equipment	Cooling	Tower Heat Reject. & Fans	Total
Electrical End-Use Total (kWH)					
Base Case	2,46,397	58,566	6,93,983	10,12,811	20,11,757
ECBC Case	2,46,397	58,566	5,04,709	6,25,013	14,34,685
Incremental Electrical Savings					
ECBC Case	0	0	1,89,274	3,76,192	5,77,072





SCREEN SHOTS SHOWING COMMANDS OF THE SOFTWARE





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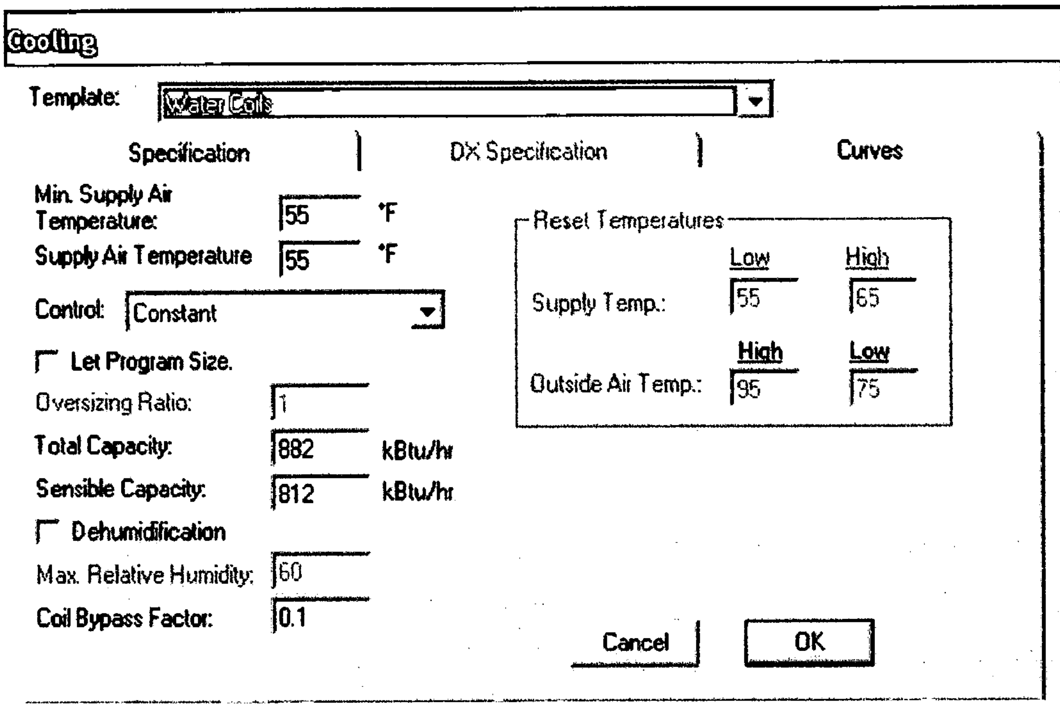

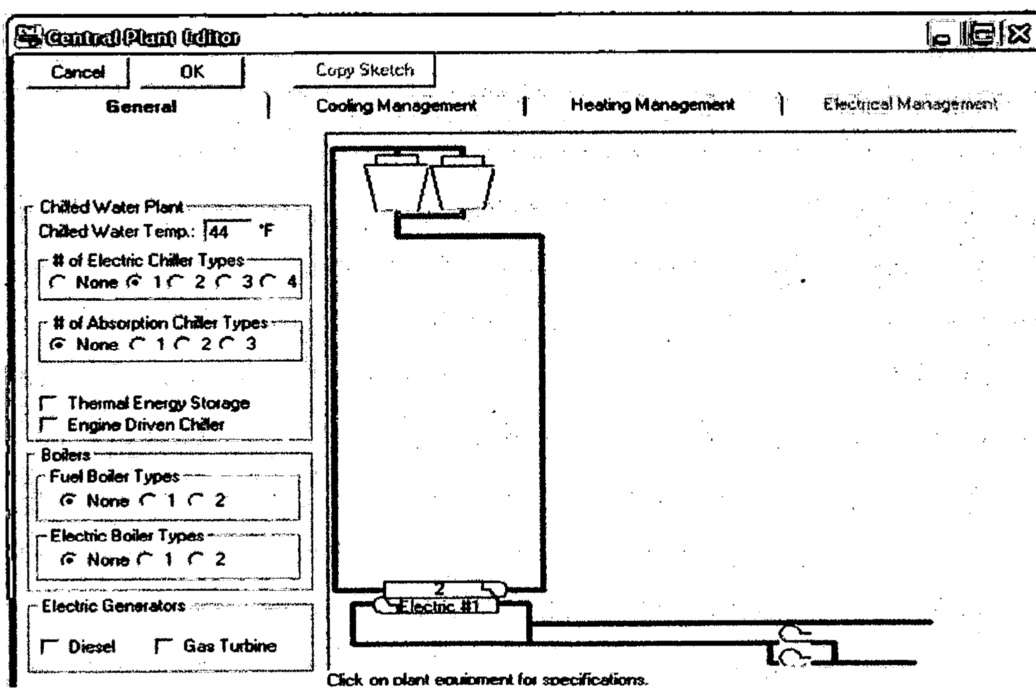

SCREEN SHOTS SHOWING COMMANDS OF THE SOFTWARE

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