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The Development of a Computer Program to Co-ordinate Early Design Stage Information

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Declaration Page

I certify that this thesis which I now submit for the examination for the award of Master of Science in Engineering, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work..

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Abstract

The reduction of the adverse effects that buildings and their services have on the internal, local and global environment is becoming increasingly important. Several methods and procedures have been adopted to encourage designers and engineers to become more environmentally friendly and energy conscious. The advance of computer simulation and modelling of buildings has been successful in addressing potential problems in the design process while providing additional information otherwise not available to the design team. However, it is the purpose of this thesis to use this information and benefits of simulation and modelling at an earlier stage in the design. This thesis endeavours to investigate the requirements and benefits an integrated Early Design Stage program would bring to a project and the design process.

As the essence of this thesis would have implications on the role of a Building Services Engineers in the design process, it was necessary therefore to identify the role currently of the Building Services Engineer and the other members of the design team throughout a project from the initial brief through to construction.

An extensive Literature Review of approximately sixty computer programs was analysed to establish the computer software programs available both commercially and educationally. This Literature Review entailed a description of the programs, their advantages and disadvantages, number of world-wide users, user expertise required and the computer language the programs are written in.

A Questionnaire/Survey was carried out on Building Services Engineers working in the industry to establish the current design procedures with respect to building services systems design and assess the industries experience and knowledge in regard to computer simulations and modelling. The results of the Questionnaire/Survey identified that an Early Design Stage tool would be beneficial to the design process and it was widely recognised the potential of such a program to tackling energy efficiency and energy reduction in buildings.

In order to emphasise the importance of computer simulation and modelling in the design of a building and its potential benefits to the design process, two case studies were investigated. Both of the case studies directly compared computer simulation of a building to traditional calculation methods.

With the completion of the literature Review, Questionnaire/Survey and the Case Studies, the need for an Early Design Stage computer program was identified. It was therefore necessary to specify the requirements of such a program. This entailed proposing the structure of a program, input and output parameters and working with my industrial partner in the development of the software.

Following the completion of the development of the Early Design Stage Computer Program, a case study on the program was carried out. This identified the benefits of the program and highlighted the advantages this new program would bring to the design team, especially in terms of the information available to the engineer, architect and the client at the early design stage.

INTRODUCTION

Research Outline

The purpose of this research is:

1. To investigate the need for a computer program, which will provide information to make early design building services and architectural decisions.
2. To specify the requirements and assist in the development of an early design stage computer program.

It should be stated initially that the investigation concentrates upon a building services engineering basis rather than a computer programming assignment.

Rationale

It is becoming increasingly important in today's climate to limit the adverse effects that buildings and their services have on the internal, local and global environments. Global energy resources such as gas, oil and fossil fuels are finite and depleting. Global warming, air pollution and climate change are adverse by-productions of power generation. Buildings and their services are major users of energy. Buildings represent a large portion of countries energy consumption, approximately 40% of total energy consumed [1]. There is potential for energy savings in buildings, primarily efficient design of the energy demands and loads, helping to reduce the building services overall plant and equipment duties.

It is recognised that current methods of building services design can lead to over sizing, over specification and over engineering of environmental systems gives rise to increased initial and operating costs. Energy costs and CO2 emissions are also increased due to low inefficiency caused by over sized central plant and distribution systems [2].

The amount of energy consumed by a building is governed largely by the building's form and thermal characteristics [3]. Thus, it is actually the building designer who has primary control over the building's energy use [4]. There are many energy analysis tools available, but unfortunately they are not oriented towards building designers and integrated into early design stage of a project. The typical tool requires a very detailed description of the building as well as the mechanical systems – neither of which are available in the earlier stages of a design decision [5] [6]. As a result, building designers find it burdensome to include energy considerations in the design process, and so energy analyses are regularly delayed until after the building has seen completely designed [7].

Building simulation programs are not recognised as design support to tools to the same extent as CAD tools or costing software [8] [9]. Evidence for poor uptake of the technology by industry can be found in literature [10] [11]

In order to remedy this situation, an integrated early design stage tool is required by the industry to provided the necessary information to the designers to effectively evaluate the building's energy use and change the building design or properties to meet an energy and cost target at the early design stage.

Objectives

The objectives of this research were as follows:

1. Investigate building energy usage and the environmental impact of buildings and their services.
2. Investigate the design team and the role of each member of the design team.
3. Conduct a comprehensive study of building services computer software available as part of the thesis literature survey.
4. Establish the role of simulation modelling of buildings in the building services industry.
5. Conduct a review of professional simulation authorities and societies.
6. Complete a questionnaire/survey of building services engineers.
7. Establish the future of simulation of building environmental performances.
8. Carry out case studies on buildings designed using computer simulation modelling.
9. Establish the leading software consultants and complete a detailed study of the software and services they provide.
10. Develop the specification for an early design stage computer program.
11. Analysis the early design stage computer software developed through means of tests and

case studies.

Methology

In order develop the need for an early design stage computer program, the author considers it necessary first of all to investigate how buildings are currently being designed, establish the role of the members of the design team and the procedures used from the concept brief to the overall construction and commissioning of buildings in a normal project.

There are currently numerous computer programs available for the design of building energy loads. Traditionally, since the initial development of computer software for the building services industry, these programs have been based upon steady state conditions within a building to establish the heating and cooling requirements. However, in-line with the development of faster processing speeds of computers, it has been possible to evaluate the energy requirements and performance dynamically through time step intervals. It was therefore necessary to identify what computer programs are being used by the building services industry and what method of design engineers use to estimate the buildings energy requirements and energy flow patterns. This was achieved by using a two-tier approach. The first tier consisted of an in-depth literature review of available textbooks, journals, conference papers and web sites. The second tier involved interviewing engineers through a questionnaire/survey. This questionnaire/survey was designed in a manner to establish engineers knowledge of simulation programs, what design method they use to establish building energy loads, and their awareness of the adverse effects that buildings and their services have on the environment.

A detailed case studies of building's which have been designed using simulation programs and compared them to buildings designed using the traditional steady state approach was carried out. This identified the benefits that computer simulation of a building's energy requirement brings to the design process and the potential reduction in the plant and energy usage that results for accurate load estimation.

The specification of the early design stage programs was then developed, incorporating the markets and industries requirements and the findings and knowledge gained through the literature review and a qualitative methodology using a Questionnaire/Survey.

Following the development of the early design stage program, a case study using an early version of the program was carried out. The objective of this was to establish the benefits and the program and identify the short falls and potential improvements.

Chapter One: Building Energy Usage and the Design Team

1.1 Buildings and Energy Usage

Buildings have a major role in our society. We all use buildings for a wide range of functions, work, entertainment, shopping, eating, etc. Up to 80% of an individuals life is spent indoors [12]. The function of a building has evolved from a simple shelter to an advanced self contained and tightly controlled environment which provides a wide variety of services to its occupants: environmental conditioning, vertical transportation, sanitation, artificial lighting, communications and security [13].

In order to provide these services, buildings consume energy through fans, pumps, boilers, chillers, lifts, motors, electrical services and generators. This form of energy within buildings accounts for up to 30 to 40% of a country's total energy consumption [14]. A US survey [15] revealed that in buildings over ten years old, 30 to 40% of the energy consumed is wasted due to the poor condition of the buildings envelope and plant. This energy wastage has major implications on the environment.

When considering the cost of a new building, some 30 up to 50% is related to HVAC systems in commercial buildings and 5 % to 10% in domestic buildings [16]. Hence, with respect to both environmental impact and economics, the ability to make sensible and well-based decisions regarding the choice and design of HVAC systems is of the utmost importance.

This inefficient use of energy within buildings also causes strains of the world's limited fossil fuel deposits. Global warming, increased CO_2 production, air pollution, acid rain and climate changes are adverse and well documented by products of power generation. It is clear that something has to be done to reduce the energy requirements and usage within buildings and prevent energy wastage within buildings.

1.2 Design Team

The design team generally consists of the following members:

- The Architect,
- The Building Services Engineer,
- The Structural Engineer,
- The Quantity Surveyor,
- The Project Manager.

All these members of the Design Team have important roles to play if the problem of energy reduction and energy wastage is to be addressed within modern buildings.

1.2.1 How Building's In General Are Currently Being Designed.

To firstly understand how buildings are being currently being designed, it is necessary to understand whom is involved in the design decisions, whom instigates the project and what are the driving forces behind the decisions made in the design process.

1.2.1.1 Building Design Procedure

The purpose of reviewing the current design process is to establish the role of the members of the design team in order to gain a deeper appreciation on how decisions are made and acted upon by the design team. It is only then that suggestions may be made on how the information transfer and co-ordination may be improved upon and at what stage is most beneficial from an energy usage and environmental performance point of view.

The following would be normal practice for medium to large sizes projects. The designers receive the commission and the design team is assembled ~ either all appointed by the client or the architect is appointed by the client and the engineers which include the Structural, Mechanical, Electrical Engineers appointed by the architect.

The architect prepares a schedule of Accommodation or Schedule contained in a Brief ~ a bound document previously drawn up by the client.

From the Schedule of Accommodation or the Brief, the architect prepares sketches of the building.

From these sketches, the Services Engineer begins the preliminary stage of the design of services,

The service's engineer estimates the accommodation requirements for the services,

More detailed plans and perspectives are produced by the architect at this stage and a preliminary application is made to the local authority,

The Quantity Surveyor begins to prepare Cost Estimate from the architectural plans and from the services engineer's report of the services cost estimation,

Once approval is obtained from the local authority, the architect makes basic decisions about the building ~ its layout, height, structure, materials, finish, glazing etc. in collaboration with the rest of the design team,

Detailed design can now commence by the engineers and the project therefore develops from here.

With this form of design process in which the services engineer works off sketches produced by the architect, the only input the services engineer has at this stage thus far is the plant and services area requirement. The service's engineer has no real contribution to the building size, shape, orientation, etc., all of which have major consequences on how the building will perform environmentally and also on the energy requirements which the building consumes. Schuler recognises the need for co-operation between architects and engineers of different fields in the planning phase and that currently building services engineers are only incorporated after the conclusion of the building design and therefore contribution to addressing environmental issues to limited [17].

The architect's decisions of the building layout, floor to ceiling heights, façade and glazing dictate the environmental system design. It is the job of the building services engineer to select plant and size the systems from here on. Very few architects would be environmentally conscious enough or have the technical knowledge to develop and design effective and efficient naturally ventilated buildings. This is not criticism on architects, it is up to engineers to inform and guide architects in the right direction. However, while the software exists to enable better design decisions, the software is designed for the detailed design stage of projects and not the critical early design stage. It is not possible to analysis quickly and readily the impact different of design decisions on the environmental, capital cost and running cost point of view.

For years the approach to designing buildings as described previously has worked and some would consider it an effective method of producing buildings. However, with the growing public concern to environmental issues such as air pollution, green house gases, acid rain and the continuing deletion the world's fossil fuel resources, it is now time to address all aspects of the building industry's approach to the design and construction of buildings. Building services engineers have to lead the way in the design process along with the architects in designing effective and energy efficient building services systems.

The author suggests that in order to incorporate a holistic approach to energy reductions and environmental design and the use of simulation in all stages of the design process, the RIBA[18] design plan of work is an ideal model. The RIBA design plan identifies three main building design stages:

- Outline Design Stage
- Scheme Design Stage
- Detailed Design Stage

Significant design decisions, which can have an influence on the energy and environmental performance of the building, can be incorporated into each of these three design stages.

Building services engineers providing a simulation service are already involved in the scheme design stage and the detailed design stage, advising the design team on design issues such as glazing type, shade and or blinds requirements and benefits, air change rate (detailed analysis), lighting control and occupancy comfort at the scheme design stage and different cooling/heating strategies, HVAC control and ventilation strategies at the detailed design stage [19].

In the outline design stage, early design stage or feasibility stage as described previously, the building services engineer can provide information or orientation, u-values, heat recovery systems, glazing area, floor plan depth etc which can have influences on the overall design of the building and the energy and environmental performance.

Chapter Two: Literature Review

2.1 Introduction

The purpose of this literature review is primarily to establish the computer simulation programs available on the market to Engineers, Architects and research students. The two different design approaches used by the industry are firstly introduced. These methods are the Steady State Calculation Method and the Simulation Method.

2.2 Steady State Design Method

The Steady State design method approach calculates heating and cooling loads based upon isolated extreme external temperatures and assumed radiation and convective transfer coefficients. The heating load is calculated generally using the Steady State U-Value Method [20]. In the calculation of the U-Value to be used in this method, it is assumed that the heat loss through the building fabric has reached steady state and the inside and outside boundary conditions remain constant.

The Periodic Steady State Admittance Method [21] is used for calculating the peak temperature in a building and the associated cooling or air conditioning load for the building. This method assumes that the outside temperatures behave as a sine wave and that the sine wave repeats periodically with a 24-hour cycle. The environmental conditions (temperature and humidity) inside the building are assumed to remain constant.

There are a number of Steady State programs available, such as Cymap, DDB and Hevacomp. These programs have been on the market for a number of years and a large percentage of all Mechanical and Electrical Consulting Engineering companies throughout Ireland and the UK are using these steady state design tools, particularly the Hevacomp design software to some extent or a least have the package available to them in their design offices. The author has tested Hevacomp and Cymap as they are the main design tools currently used by the building services industry. These steady state programs are easy to use while being to a certain degree quiet cumbersome. The information produced is limited, only identifying the peak heating and cooling loads and providing limited information on the energy flows that occur within a building and the multiply inter-reactions between construction and gains/losses within the space. Different design strategies and cost analysis cannot be easily and readily compared and the uniqueness of the design cannot be addressed.

With the advancing developments in the personal PC market, the number of consultants using computers has significantly increased, especially over the past ten years [22]. Nevertheless, there have not been significant advances in the basic concept of the Hevacomp software package in that time or in fact since the earliest release of the software. Indeed, the software package has had many facelifts and the processing speed has tagged along with developments and advances in computing power and speed. However, behind these facelifts still remains the same fundamental formulae, especially those formula for calculating heating and cooling loads within buildings. Consequently, the software is a steady state design package, with no capacity for dynamic calculations of weather and building function or an ability to check comfort levels or compare different design options.

It appears that Hevacomp have realized the limitations and interestingly all their latest releases and improvements, in general, have been with the compatibility of their software and CAD packages. These are and will continue to be beneficial to the draughting end of the design process, but there contribution to reducing buildings detrimental effect on the environment and reducing CO2 emissions from a building will be negligible. The processing speeds need only be so fast for the end users and so it is the authors opinion that Hevacomp will continue to have facelifts, improve its processing power and speed and increase its interoperability between CAD packages and have links with the internet.

2.3 Simulation Design Method

Building energy simulation is a powerful method for studying energy performance of buildings and for evaluating architectural and building design. Complicated design problems can be investigated and their performance can be quantified and evaluated. It is also a useful tool for developing a better understanding of the building performance. Energy analysis can help designers develop effective building form and design strategies.

An ASHRAE Task Group [23] formulated a definition of plant or system simulation applicable to "Energy Requirements for Heating and Cooling of Buildings" as:

"... predicting the operating quantities within a system (pressures, temperatures, energy-and fluid flow rates) at the condition where all energy and material balances, all equations of state of working substances, and all performance characteristics of individual components are satisfied."

2.3.1 Basic Theory of Building Energy Simulation

Building energy simulation is based upon the load and energy calculations in heating, ventilating and air-conditioning (HVAC) design. Load calculations determine peak design loads for equipment and plant sizing. Energy calculations estimate annual energy requirements to the required loads. Information provided from simulation results include:

- Building energy consumption data,
- Indoor environmental conditions,
- Equipment and plant performance.

The targets of simulation analysis include:

- To provide comfortable indoor conditions for an acceptable fuel consumption.
- To optimize the system performance.
- To compare design options based on life cycle costs.

The integration of simulation modeling into the building design process is increasing, but is not yet standard practice. Design teams working on 'ordinary' buildings are less likely to make use of modeling software than the designers of prestige or complex buildings [24].

2.4 Simulation Versus Steady State

The debate of Simulation Versus Steady State is well documented and discussed. Clarke 1985 [25] discussed the limitations of the Steady State approach to building services energy load calculations. It is recognised that simulation programs and software provide the design team with a wide range of information guiding towards more effective and efficient design solutions [26].

Baring this in mind, it is sometimes questioned whether the answers that complex building simulation programs are any more representative of the situation in real life than simpler steady state alternatives.

Results from simpler methods may agree with 'rule of thumb' results but this information has never been tested or validated and will not really give an insight into the interesting/important design parameters and information. Steady State and simpler methods are based upon certain assumptions, for example, the wind speed and direction used in the calculation of the convective heat transfer coefficient is at a velocity of 2 m/s [27]. This heat transfer coefficient is an intrinsic part of the external resistance of the structure and ultimately the u-value calculation. Furthermore, the admittance method is based upon a cyclic temperature profile. Clearly these conditions cannot be tested or validated against actual building energy profiles or results and their usefulness must come into question also.

Simpler methods cannot take account of what happens the day before and only provide general information but cannot provide specific information for the building that is being designed in terms of incidental gains profile, site shading etc. Each building design will most likely have some unique site characteristic in terms of shading provided by other buildings and this makes it unique. The LT method [28], which is an example of a Simpler Method, can provide early design stage information in terms of % glazing, layout dimensions, orientation but the uniqueness of the design cannot be included.

Nowadays designers need to be able to check if proposed natural ventilation strategies will work or if a mixed-mode design is required. Thus, need to be able to assess mixed mode systems. For the assessment of natural ventilation systems the method must be able to take account of stack-driven airflow, cross-flow, atria design, thermal mass, night cooling etc. It is also necessary to be able to quantify comfort temperatures over the annual occupied period. CIBSE latest Guide A Section 1.3 [29] recommends that a dry resultant temperature of 25^{0}C should not be exceeded for more than 5% of the annual occupied period. If there is a lot of glass in the building it is necessary to use dry resultant temperature to take account of the radiant heat effect from the glass that has absorbed solar radiation. Simpler methods cannot perform sufficient studies on varying situations and therefore incapable of providing or analyzing these types of results.

Comfort conditions will be affected by the varying outside condition. The dominant loads are normally incidental gains and solar radiation. It is necessary to divide incidental gains into their convective and radiant elements to be able to assess if the thermal mass and night cooling strategies can cope with them. For solar radiation it is necessary to separate this into direct and diffuse radiation to determine if brise soleil arrangements is effective in reducing the direct solar gain to the building. Accurate orientation and form of the building is also necessary for this. For good comfort analysis, the possibility of air movement coincident with high temperatures also needs to be addressed. Simpler methods are not capable of providing this range and type of information, which have a significant impact on a buildings final energy usage and efficiency.

2.5 Simulation Programs Available

Computer simulation programs available on the market are critically analysed in this section, identifying the advantages and weaknesses of each program while giving a detailed description of the operation of each individual program, in doing so provide a critical appraisal of the software on the market.

Throughout the literature review, over sixty-computer program were analysed. Only the relevant up-to-date programs included are included in Table 2.1 below as a number of the programs analysed during the course the literature review were either old versions of current programs or no longer used by the industry. Refer to Appendix A for detailed description of each program

At present there are many different types of simulation software and programs; each of them with there own characteristics tools and they are also developing continuously. Some simulation tools reviewed would be considered very sophisticated and complicated and are usually used for research purposes in the past, such as ESPr [30], DOE-2 [31], BLAST [32 and TRNSYS [33]. In recent years, with the fast development of computing technology, they are beginning to be noticed by the average-building designers.

Table 2.1: Simulation Programs on the Market

	Program Name	Description	Users	Source
1.	ADELINE	Lighting and Day-lighting design Tools	Engineers and	International Energy Agency

			Architects	
2.	ASEAM	Annual Energy Evaluation Tool.	Engineers and Architects	USA
3.	BLAST	Hourly Simulation of buildings to accurately estimate building's energy requirements	Engineers	USA
4.	Building Design Advisor (BDA)	Software program that supports the integration of multiple building models and databases used by analysis and visualisation tools	Engineers and Architects	USA
5.	BUS++	Performs building energy, ventilation, noise level and indoor air quality simulations	R&D, scientists, engineers and education	Finland
6.	CBIP Comply	Software designed to demonstrate and document compliance with the requirements of Commercial Building Incentive Program	Engineers and Architects	Canada
7.	COMIS	Airflow Distribution Simulation Tool	Architects, HVAC engineers, physicists.	USA
8.	DEROB-LTH	Dynamic Simulation of different building designs	Students, Researcher and energy consultants	USA

9.	DesiCalc	Allows hourly simulations of desiccant based equipment	Energy Engineers	USA
10.	DOE-2	Hourly, whole-building energy analysis program calculating energy performance and life-cycle cost of operation.	Engineers and Architects	USA
11.	Energy Scheming	Energy Efficient Building Analysis program	Architects	USA
12.	ENERPASS	Detailed building energy simulation program for residential and smaller commercial buildings.	Engineers and Architects	USA
13.	Energy-10	Design tool for smaller residential or commercial buildings, which performs whole-building energy analysis, including dynamic thermal and daylighting calculations.	Engineers and Architects	USA
14.	ESP-r	Performs sophisticated High level Thermal Dynamic Simulation of Building Energy Flows	Simulation Engineers & R&D	Scotland
15.	Ergon	Running cost/Tariff Analysis, CHP studies and energy consumption studies.	Engineers	UK
16.	EZDOE	Calculates hourly energy and life-cycle cost use of buildings	Engineers and Architects	USA
17.	FEDS	Provides comprehensive method of quickly and objectively	Engineers and	USA

		identifying energy improvements of buildings	Architects	
18.	FSEC 3.0	Finite element analysis program on buildings	Engineers, researchers and educators	USA
19.	Green Building Advisor	Identifies strategies that can improve the environmental performance of a building	Architects and Facility Engineers	USA
20.	HAP v4.0	Performs energy simulation of building heat flow and equipment performance.	Engineers	USA
21.	HEAT2	Calculates Two-dimensional transient and steady-state heat transfer within buildings	Engineers, researchers and educators	USA
22.	HEAT3	Calculates Three-dimensional transient and steady-state heat transfer within buildings	Engineers, researchers and educators	USA
23.	HCACSIM+	Performs simulation models of a buildings HVAC loads, the building shell, energy analysis and control system algorithms.	Engineers, researchers and educators	USA
24.	HOT2000	Energy analysis and design software for low-rise residential buildings.	Engineers and Architects	Canada
25.	HOT2XP	An energy analysis program for use in houses	Renovators, builders, utilities, home inspectors,	Canada

			design evaluators, engineers and architects	
26.	Jasmine	Detailed Fire and Smoke Simulation. Studies.	Engineers	UK
27.	Load Express	Calculates detailed HVAC load reports for heating, cooling and airflow capacities	Engineers	USA
28	MacroFlo	Simulation of infiltration and inter-zone bulk air flow..	Engineers	UK
29	MARKET MANAGER	Simulates integrated building performance including load, system, and plant calculations modeled on an hourly basis.	Energy Engineers	USA
30.	MicroFlo	Computational Fluid Dynamics (CFD) program	Engineers	UK
31.	Micropas4	Detailed energy simulation program, which performs hourly calculations to estimate annual energy usage for heating, cooling and water heating in residential buildings.	Energy Engineers	California
32.	NewQUICK	Thermal design and simulation tool capable of calculating loads and energy consumption	Engineers and Architects	USA
33.	Physibel	2-D and 3-D steady state heat transfer program for building details, thermal bridges, window frames and enclosures.	Engineers and University and research	USA

			institutes.	
34.	Radiance	Advanced lighting simulation and rendering package which calculates spectral radiance values and spectral irradiance for interior and exterior spaces.	Engineers and Architects	USA
35.	REM/Design	Highly sophisticated residential energy analysis and code compliance software.	Energy Consultants	USA
36.	ROVE	Visualisation and animation of 3D geometry models.	Engineers	UK
37.	SPARK	An object-oriented program that allows the user to quickly build models of complex physical processes by connecting calculation modules from an object library	Building technology researchers and energy consultants.	USA
38.	Simulex	Occupant movement and evacuation study	Engineers and Fire Consultants	UK
39.	Solacalc	Simulates passive solar houses by calculating heat losses and solar gains in residential buildings.	Architects and Builders	UK
40.	Suncast	Solar mapping and insolution studies	Architects and engineers	UK
41.	Superlite	Daylighting and electric analysis program which calculates interior illuminance levels in complex building spaces.	Architects and Lighting Designers	USA

42.	System Analyser	This package for load calculation and energy and economic comparative analysis. System Analyser permits a quick evaluation of virtually any building, system, and equipment combination.	Utility Companies.	USA
43.	TARP	Thermal and Air Flow energy analysis program.	Engineers and Architects Students.	USA
44.	TAS	Performs thermal analysis of Buildings.	Building Services Engineers and Architects.	UK
45.	TRACE 600	HVAC system comparison tool.	Engineers	USA
46.	TRNSYS	Performs thermal energy system simulations to aid select HVAC plant.	Engineers	USA
47.	Tsbi3	Evaluates Building energy loads.	Engineers	Denmark
48.	VisualDOE	Energy simulation program used for exploring HVAC system design alternatives	Engineers	USA

2.5.1 Comments on Simulation Programs

From the author's investigation into the above programs, it was established that all of the simulation programs while differing in their programming language, application, databases available and complexity of operation can be divided into two categories. The simulation programs are either designed for the detailed design stage of a project or are developed for research purposes. It is recognised from this detailed review that none of the programs have the ability to analyses different design decisions quickly and efficiently that may arise at an early stage of the design process and integrate early design stage information with other software used in later design stages.

Very few of the programs have been developed with interoperability and integration in mind. This view is shared in a number of other studies in which it is stated that simulation should not be only for final performance confirmation but as a integrated element of the design process [35] [36] [37].The ability to transfer and share information between programs has only been incorporated into the suite of computer programs developed by Integrated Environmental Solutions (IES) in Scotland and the Lawrence Berkeley National Lab in the US. Both have design and developed their range of software to operate around a central integrated data model and databases. Hence, it is possible to share the same model used for thermal simulations as those for natural day-lighting simulations for example. Lawrence Berkeley National Lab has developed a computer program called the Building Design Advisor (BDA) [34].

The BDA is a multimedia based integrated building design support environment that assists building designers with the integrated consideration of multiple design solutions with respect to multiple design criteria in the design process. It is linked to multiple analysis tools and databases. It is planned that future versions of BDA will be linked to DOE-2, cost estimating and environmental impact modules, building rating systems, CAD software and electronic product catalogues.

Integrated Environmental Solutions (IES) based in Glasgow, Scotland have developed their simulation tools further than the BDA software computer programs. A more comprehensive review of IES and their suite of computer simulation programs are described in Chapter 4.

2.6 Simulation Societies

As part of the literature survey and review, all societies with links with computer simulation and the development of simulation of buildings have been investigated and researched. The leading simulation group widely recognized among simulators and environmentally conscience engineers is called The International Building Performance Simulation Association (IBPSA) [38].

2.6.1 IBPSA's Vision

IBPSA was founded in 1986 to advance and promote the science of building performance simulation in order to improve the design, construction, operation and maintenance of new and existing buildings worldwide. It is the aim of IBPSA to provide a forum in which in the promotion and development of building simulation technology for researchers, developers and practitioners can review building model developments, facilitate evaluation, encourage the use of software programs, address standardization, accelerate integration and technology transfer. IBPSA's aim is that in the future governments, industry, utilities and academic institutions will look to IBPSA for guidance in determining policies, areas of research, and application development in building simulation.

IBPSA act as a clearing-house for software products and services in building simulation. IBPSA hope to provide a framework for strategic alliances for information in Research and Development and Technology Transfer.

2.6.2 IBPSA's Goals

The following goals were identified at the inception of IBPSA:

1. Identify problems within the built environment that may be solved by improved simulation tools and techniques;
2. Identify the performance characteristics of buildings on which simulation should be focused;
3. Identify building performance simulation research and development needs and transfer new developments to the user;
4. Promote standardization of the building simulation industry; and
5. Inform and educate its members and the public regarding the value and the state-of-the-art of building performance simulation.

Functions:

The key functions of IBPSA are to:

1. Seek advice of building designers, owners, operators, and developers, regarding the proper role of building performance simulation;
2. Promote simulation through education programs, advertising, and other means for the good of the building simulation industry;
3. Building a scientific base upon which all interested in building simulation may draw;
4. Develop software framework from which improved building performance computer programs may be developed;
5. Enhance the proper application of simulation tools;
6. Help achieve an integration of computer aided drafting (CAD) with engineering and performance software by identifying standard methodologies and data files;
7. Prepare and/or sanction training courses, technical forums, journals, newsletters and other material to educate its members and the public regarding building performance simulation;
8. Sponsor/co-sponsor research and development projects to improve simulation tools and practices;
9. Prepare standards for practice of building performance simulation;
10. Survey available simulation codes and publish descriptions of the characteristics of the codes;
11. Serve as a clearing house for public domain computer code in building performance simulation;
12. Assist private and public sector computer program developers to learn and use public sector codes thereby stimulating the development of new tools and methods;
13. Organize building elements terminology and other definitions to achieve the necessary standardization that will service the industry;
14. Assist codifying organizations to understand and interpret standards of practice prepared by the IBPSA;
15. Support various communication media including an active electronic network to keep its membership informed; and
16. Promote the exchange of information on building performance simulation internationally and with other disciplines.

2.6.3 IBPSA'S Affiliate Members

IBPSA has a number of affiliate members, which include:

- IBPSA Ireland (Recently formed). The author is one of the founding members, along with Conor Clarke, Vincent Murray, Ken Beattie, Orla Coyle, John Brady, Tom O'Brien and Denis Malone.
- Building Energy Performance Analysis Club (BEPAC-IBPSA UK)
- IBPSA Australasia
- IBPSA France

To date IBPSA has held international conferences in Previous conferences in Vancouver, Canada (1989), Nice, France (1991), Adelaide, Australia (1993), Madison, United State (1995) and Prague, Czech Republic (1997) and most recently in Kyoto, Japan.

2.7 Building Energy Efficiency Standards

As part of this literature review, a study into any relevant simulation standards that exist and the organizations behind the standards was performed.

Nowadays, the developing and implementation of building energy efficiency standards is more complicated than the older ones, which are often prescriptive in nature, and energy simulation software is often required for developing them [39]. Through the comparison and analysis of energy targets, one can determine whether the energy efficiency requirement has been satisfied or not. The future trend of Building Energy Efficiency Targets Standards is to adopt a "performance based" approach and it will rely heavily on the support of simulation techniques.

The UK and Ireland have to date not produced recently an energy standards that could be related to simulation tools and programs. The following is the energy codes and standards that engineers adhere to:

- *British Standard 8207: 1985, Energy Efficiency in Buildings*, British Standards Institution.
- *Energy Design Guide: Design Guide to BS8207: 1985, British Standards Code of Practice for Energy Efficiency in Buildings*, British Standards Institution.
- Building Regulation Part L.
- CIBSE Building Energy Code
- Part 1 - Guidance towards Energy Conserving Design of Building and Services (1977)

- Part 2 - Calculation of Energy Demands and Targets for the Design of New Buildings and Services
- Section (a) Heated and Naturally Ventilated Buildings (1981)
- Part 3 - Guidance towards Energy Conserving Operation of Buildings and Services (1979)
- Part 4 - Measurements of Energy Consumption and Comparison with Targets for Existing Buildings and Services (1982)

2.8 Conclusion to the Literature Review

There are many simulation programs and tools available for engineers and building designers, which not only enhance the quality of information but also have significant impact of the buildings final energy and environmental effectiveness and efficiency. The importance to provide information earlier in the design process is also recognized and an integrated approach is required to achieve the maximum benefits. A number of research teams are currently investigating this topic, such as the Building Design Advisor. Nevertheless, this critical review and analysis of the simulation software and programs has identified that no ready to use design support tool for the early design stage that can be fully integrated into the full design process is available.

3. Questionnaire/Survey

3.1 Building Services Engineer Questionnaire

3.1.1 Introduction

Initially to establish the scope of this research Masters, the author felt that it is important to get an appreciation of the current working environment with regard to Building Services Engineers methods of designing buildings and the awareness of Building Services Engineers to alternative methods of design. This was necessary to establish the Engineers knowledge of Simulation Modelling programs, their awareness of the detrimental effect that buildings have on the environment and the benefits of co-ordinating early design stage information to enhance the environmental performance of buildings.

The questionnaire was designed in a fashion that would challenge the Building Services Engineer into addressing why they use their current method of design and by doing so ask themselves questions regarding their current methods validity and effectiveness. The questionnaire also was structured into yielding accurate and honest responses from the engineers to give a good indication of the current design market throughout various levels of experience and years of designing. The questionnaire is included in appendix B along with a number of answers to the questionnaire that were received from Building Services Engineers.

A number of the larger consulting design offices in Ireland were targeted and a few smaller offices to get a cross section and accurate span of the market.

3.1.2 Results

The responses received back produced some very interesting results. See Table 3.1 for the results of the survey. Due to the varying experience and age difference between those surveyed and in order to easily categorise the responses, the result table is separated into different age groups;

- 20 years old to mid twenties ~ young engineers and recent graduates

- Mid twenties to forty ~ experienced engineers designing several years and project engineers
- Forty plus ~ generally established project engineers and directors

From many of the answers received, it became obvious that engineers select between three different methods of calculation when designing:

CIBSE computer programs ~

HEVACOMP & HSTAR
CYMAP

Excel Programs based on CIBSE calculations and assumptions.

CIBSE Manual Calculations ~

Rule of Thumb calculations (based on W/m^2 basis)

Simulation Modelling Programs ~

ESP
Macroflo

Suncast

It was found that there was no specific preference between the different ages when design using CIBSE computer programs and CIBSE manual calculations. However, only one engineer whom designs consistently using simulation programs was surveyed which gives an insight into the smaller percentage therefore of engineers designing using simulation in Ireland.

Table 3.1: Questionnaire/Survey Results Table

		20 - 25	26 - 40	40 plus	Comments
Design Method?					
	CIBSE ' Rule of Thumb '	54%	100%	100%	No engineer over the age
	CIBSE Computer Program	40%	0%	0%	of 25 designs building loads
	Simulation	6%	0%	0%	using simulation programs

		20 - 25	26 - 40	40 plus	Comments
Why do you use this method?					
	Available in Office	72%	100%	100%	
	Understand the Method	14%	-	-	
	Method is easy to use	14%	-	-	
Is the Method the most accurate, efficient and best available?					
	CIBSE ' Rule of Thumb '	Yes - 0%	Yes - 0%	Yes - 0%	Note that all engineers using
	CIBSE Computer Program	Yes - 0%	-	-	the CIBSE methods recognise
	Simulation	Yes - 100%	-	-	that it is not the most accurate.
Percentage Engineers comfortable using their method of design					
	CIBSE ' Rule of Thumb '	Yes - 66%	Yes - 100%	Yes - 100%	The majority of CIBSE engineers
	CIBSE Computer Program	Yes - 66%	-	-	are comfortable however with
	Simulation	Yes - 100%	-	-	the CIBSE method.
Awareness of Simulation design methods and its benefits to the design process?					
	CIBSE ' Rule of Thumb '	Average	Average	Average	Note that Engineers using
	CIBSE Computer Program	Average	-	-	simulation software have a very
	Simulation	Excellent	-	-	good knowledge of other methods
					available.
Percentage of Engineers who have designed using Simulation?					
	CIBSE ' Rule of Thumb '	Yes - 0%	Yes - 0%	Yes - 0%	No engineers who currently design
	CIBSE Computer Program	Yes - 66%	-	-	using CIBSE 'Rule of Thumb' have
	Simulation	Yes - 100%	-	-	designed using simulation.

		20 - 25	26 - 40	40 plus	Comments
Percentage of Engineers who would design using Simulation?					
	CIBSE ' Rule of Thumb '	Yes - 100%	Yes - 100%	Yes - 100%	All engineers would design using
	CIBSE Computer Program	Yes - 100%	-	-	simulation.
	Simulation	N/A	-	-	
Is it worth while learning Simulation Programs?					
	CIBSE ' Rule of Thumb '	Yes - 100%	Yes - 60%	Yes - 60%	The majority consider simulation
	CIBSE Computer Program	Yes - 66%	-	-	to be important to learn.
	Simulation	Yes - 100%	-	-	
Should Building Services Engineers have more of an influence at the Early Design Stage?					
	CIBSE ' Rule of Thumb '	Yes - 100%	Yes - 100%	Yes - 100%	All engineers surveyed believe that
	CIBSE Computer Program	Yes - 100%	-	-	Building Services Engineers should
	Simulation	Yes - 100%	-	-	have more influence at the early
					design stage of a project.
Do you care about the Environment?					
	CIBSE ' Rule of Thumb '	Yes - 100%	Yes - 100%	Yes - 100%	All engineers surveyed ***CARE***
	CIBSE Computer Program	Yes - 100%	-	-	about the environment.
	Simulation	Yes - 100%	-	-	
Would a program that showed the difference between CIBSE and Simulation be useful?					
	CIBSE ' Rule of Thumb '	Yes - 100%	Yes - 100%	Yes - 100%	All engineers surveyed identify a
	CIBSE Computer Program	Yes - 100%	-	-	program which can compare both
	Simulation	Yes - 100%	-	-	design methods as important.

3.1.3 Conclusions

Apart from the one engineer surveyed who had vast experienced using thermal simulation programs, the majority of Building Services Engineers had little or no experience of designing the buildings heating and cooling loads using simulation programs. The reasons for lack of thermal simulation design practice in this country can be attributed to several reasons in the author's opinion and the questionnaire answers would seem to verify this. Firstly, there are a large number of designers whom used CIBSE methods, either 'Rule of Thumb' or programs such as DDB, HEVACOMP or CYMAP because it was the only available method of designing in their particular offices. They appear to have knowledge of simulation, and by that, they seem to know the word 'simulation'. There was very little understanding of the actual running of simulation software and the vast amounts of information available to designers by using such programs as IES 4D<Virtual Environment>. When asked the question:

" What projects to you foresee simulation being useful? ",

The predominant response from the designers was that only considered the design of large Naturally Ventilated buildings as ideal for thermal simulation attention. Interestingly the one and only full time simulation user considered all buildings, simple or complex to warrant some form of simulation in their design. The engineers were unaware of every day problems that arise in the design of buildings that simulation programs can answer. For instance:

- What is the optimum plant start time for energy saving
- When do the peak plant loads occur and what are the rank-ordered energy flows that constitute the peak load
- How will comfort levels vary throughout the building
- What will be the effect of some design change, such as increasing wall insulation, changing the glazing type or distribution, re-zoning the building, re-configuring the plant or changing the control regime.
- How temperature stratification in terms of zone sensor and terminal unit location effect energy consumption and comfort control
- What contribution does building infiltration and zone coupled air flow make to total boiler or chiller load and how can this be minimised

- What is the contribution to energy saving of a range of passive solar features
- What is the optimum arrangement of constructional elements to encourage good levelling and hence efficient plant operation
- Which heat recovery system performs best under a range of typical operating conditions.

It could be easy to criticise those design engineers for not using simulation programs and for their little understanding of the simulation programs themselves, however to a large extent design engineers, especially in today's climate have little or no time to spend developing new skills such as learning new programs. The responsibility should be up to Professional Bodies and CIBSE to encourage more effective and efficient design of buildings through the use of simulation programs. IBPSA was set up for this particular reason, refer to chapter 2. Nevertheless, the are still some design engineers aware of the simulation programs on the market, mainly the under 30 group of engineers. However, until provided with the software by the companies they work for and until intense training courses are provided, these band of innovative engineers simply can not take advantage of the suite of programs out there on the market.

Conventional methods of designing buildings, CIBSE methods, especially 'Rule of Thumb' methods are simpler and less easy to make mistakes, and in most normal circumstances, they are rarely significantly wrong. However, they can lead and generally do lead to over design [40]. This has serious adverse effects on the environment when the scale of development of buildings is taken into consideration. Over design not only increases the capital costs and the building services, it also leads to plant inefficiencies, which results in increased energy wastage and operating costs. The results from the questionnaire would seem to verify this and to a large extent designers are aware of this adverse effects. This begs the question why they still continue to design using the CIBSE methods. There is obviously a vacuum in the industry and an early design stage program would seem to be the answer to increase the confidence of engineers and encourage them to use simulation methods when designing.

Simulations are potentially more accurate and provide the designer with a much greater insight into the performance of the building under normal conditions and extreme stressed conditions. However they are less robust: there is a real chance that they will be seriously misleading ~ of only by their complexity and an error by the modeller [41].

It appears from interviews with the Building Services Engineers and from the answers to the questionnaire, the majority of Engineers would welcome the opportunity to design using thermal simulation.

It therefore seems that there are two approaches in which can be taken to encourage designers to use Simulation to design buildings:

1. All simulation and modelling of buildings be carried out by professional and experienced consultant simulators / modellers.

2. A program, which would encourage designers to progress from conventional CIBSE Guide method to simulation, programs. A program that could run off the same input information and yet give results from both would best serve this.

The attitude of many engineers and the industry as a whole towards simulation appears to be sceptical to say the least. There are 'barriers' holding back designers, mistrust in the answers provided through simulation, purely based upon the fact that the simulation loads produced are lower compared to CIBSE loads answers, therefore they are wrong. Considering most have little knowledge or understanding of simulation and simulation programs, this would appear to be a somewhat an uneducated response.

Interestingly, most design engineers considered thermal simulation to be more beneficial and more advantageous to the overall design, although some of those surveyed only have poor concept simulation programs. All designers would consider using thermal simulation at some stage, which is encouraging.

However, one of the most interesting results from the questionnaire is that all of those surveyed considered the development of a computer program in which direct comparisons between CIBSE designed calculations and Simulation designed calculations would be most beneficial. It would seem to me the fact that all would use thermal simulation suggests that the industry is more than willingly to design using simulation. There has to be a computer program therefore that will 'bridge the gap' or break down designers barriers towards their lack of confidence in simulation loads is essential. This would appear to be more important now than co-ordinating 'Early Design Information', which is itself also important in helping to reduce buildings environmental impact on the local, internal and global environment. However, only one step can be taken at a time, and that the introduction of designers to simulation is paramount. Only once the designers are comfortable with simulation and realise simulation benefits to the overall design, that early design information co-ordination can be addressed.

Encouragingly, all engineers surveyed felt that Building Services Engineers should have more of an influence at the early design stage of a project. From discussions with those surveyed, they recognised that identifying potential problems and highlighting energy efficient design parameters at an early stage in the design process leads to better designed buildings. However, there simply is no software available to convince architects and client of "the right way to go" at the earlier design stage quickly and efficiently. Therefore, in general the Building Services Engineers can only lend advice based upon prior experience to the design team, if requested, at the early design stage. It is obvious therefore, that a program which enhances the design of a building at the early design stage is extremely beneficial and urgently required.

Researchers have recognised the need for an early design stage tool, which can be integrated into the design process and have investigated what it takes to advance the use of design tools, presuming that this will lead to improved building performance. International workshops were held on the next generation building energy simulation tools inviting both developers and users [42]; surveys among users of simulation software were executed in New Zealand and USA to determine which improvements they seek to the simulation tool they regularly use [43]; and various interviews of practitioners on use of a range of different design decision support tools were done in New Zealand as well [44]. The main results of the workshops, surveys and reviews lead to the conclusion that the user interface is critical for the success of any simulation tool and that tools for ensuring quality are required. De Groot (1999) recognised this and furthermore identified often the participants involved in the early design stage are not able to understand the impact of their design decisions; not only on their own design task in the following stages of the process, but also on other participants' field of work [45].

The industrial requirements for an integrated early design stage program would seem to be of paramount importance based on the questionnaire/survey, the surveys and research carried out by others [46]. It is accepted that best decisions for the project are achieved using integrated software tools at the early design stage.

It is also recognised that one of the problems in early phases of design buildings is making reasonable accurate estimation of costs and performance on basis of a proposed spatial structure [47].

A more integrated approach is required for the industry, which encompasses all-important information such as capital and running costs, energy usage, which have an impact on the building design decisions and that is easily communicated and understood by the design team.

Chapter Four: IES Software

4.1 Introduction

The purpose of this chapter is to introduce the author's industrial partner for this thesis, Integrated Environment Solutions (IES). The literature survey in chapter two-highlighted IES software as the most advanced software in the field of building environmental performance. It is the intention to give a comprehensive appraisal of IES, which includes their software, history, market, achievements and simulation and consultancy experience.

4.2 History of IES

IES was established in 1995 based on research that took place at Strathclyde University in Glasgow. IES have developed the world's first <Virtual Environment> for building designers to assess the performance of a proposed or existing building.

In 1996, IES purchased Facet from Oscar Faber plc with a family of related software products. IES have set up international agents and distributors to facilitate their global expansion in countries such as, for example, Ireland, Malaysia, Singapore and Hong Kong.

4.3 IES Services to the Building Market

IES supply an ever-competitive industry with invaluable software tools to assist productivity. These application tools are state of the art, powerful, and highly flexible, enhancing communication between the design team and the client. Their software helps building designers analyse many important issues such as, whether air conditioning is required, or if natural ventilation is a viable option, the possibility of reducing artificial lighting by utilising the natural light available. The <Virtual Environment> has many benefits to offer the Architecture, Engineering and Construction industries (AEC sector).

The <Virtual Environment> provides high quality information for the design team and has a proven capital and running costs, The <Virtual Environment> has ability to minimise the environmental impact of buildings.

As well as supplying clients with first class software, IES also provide a comprehensive design support consultancy service to the construction industry with the <Virtual Environment>.

4.4 IES's Market

IES deals with the AEC sector, Architecture, Engineering and Construction industries. The following types of organisations use the <Virtual Environment> to substantially increase their productivity and reduce their costs:

- Architects and planners,
- Building Services and Environmental Engineers,
- Property Developers,
- Building Owners,
- Facilities Management,
- Controls Companies,
- Contractors,
- Design and Build Contractors,
- Retail,
- Commercial,
- Industrial
- Health,
- Education,
- Local Authorities

4.5 IES'S Experience

IES has worked on many high profile projects such as:

- The BlueWater Shopping Mall (the largest in Europe),
- The Royal Albert Hall,
- The Millennium Dome.

The IES team's expertise and experience in this field, which combined is over 175 man-years, is reflected in the quality of both their software and service.

4.6 Corporate Accomplishments

The initiative and integrity of IES has been recognised and rewarded accordingly:

- August 1996 - SMART Award from the Scottish Office.
- Glasgow Start-Up Business of the Year Award for 1996.
- Glasgow winner of the John Logie Baird Award for innovation, and came third in the national finals. April 1997 - SPUR grant awards of £102k to further develop the SAFE software.
- November 1998 - Scottish Building & Construction Award for IT Innovation

4.7 The IES<Virtual Environment>

IES has vast experience in the development and use of Computer Simulation to model the performance, operation, control and visualisation of buildings. Based upon this experience, IES has developed the world's first Integrated Building Design System built upon dynamic simulation software for assessing building performance. This unique software system is called IES<Virtual Environment> and is integrated with other software tools such as a CAD system. IES<Virtual Environment> system allows the client and his design team to explore all of these parameters (using precise simulation) and arrive at the correct solution without guesswork or rules of thumb. The <Virtual Environment> supplements and complements the designers intuition and feel for the design.

4.8 Components of the IES<Virtual Environment>

Currently the following elements constitute the <Virtual Environment> system. Refer to Appendix C for an more detailed investigation to the programs listed below.

Product	Description
ModelBuilder	4D Model Builder will be used to construct all required IDM

RADIANCE	Photo-realistic daylighting and artificial lighting simulation. The information generated is extremely beneficial, not only for the lighting engineering purposes but for the accurate visualisation of the building interior and/or exterior. Also suitable for glare studies.
SunCast	Solar mapping and insolution studies. SunCast will be used to analyse any shading regimes imposed on the model from external surroundings or from any external fixed shading devices.
MacroFlo	Simulation of infiltration and inter-zone bulk air flow. MacroFlo solves the air leakage network for a building to dynamically predict the bulk infiltration and internal air flow between zones as a function of buoyancy and wind pressure forces. When used as part of ESP (see below) the information reduces the requirements for CFD and the information acts as boundary conditions for CFD.
MicroFlo	MicroFlo has been developed specifically for the analysis of air movement within buildings based upon Computational Fluid Dynamics (CFD) techniques. The user interface includes automatic grid generation and an interactive module shaded coloured contours of temperature, velocity or concentration across a slice (i.e. section in plan or elevation)
ESP	Simulation of building energy and occupant comfort. ESP permits the user to conduct a high integrity, first principle appraisal, modelling all aspects of the energy processes in a building simultaneously through time. Many design problems (for example fabric design, comfort or condensation assessment, control system appraisal) can only be meaningfully assessed in this way. ESP can be used in tandem with MacroFlo to conduct combined

	dynamic thermal and macroscopic airflow simulations.
Ergon	Running costs/Tariff Analysis/CHP feasibility/Primary Energy Consumption/Environmental gas emissions. Ergon is a unique computer software program for building designers and energy managers, providing them with the ability to assess the feasibility of various design options quickly and rapidly in terms of costs and pay-back.
ROVE	Visualisation and animation of 3D geometry models displayed in full colour with textures and realistic lighting effects. Facilities for displaying air flow patterns for MicroFlo and solar mapping from SunCast.
JASMINE	Detailed Fire and Smoke Simulation. Uses MicroFlo interface to define problem and display results. Operated in conjunction with the FRS.
Simulex	Occupant movement and evacuation.

Table 4.1: Suite of Programs in IES<Virtual Environment>

One of the major benefits of the <Virtual Environment> is a high degree of Product Synergy. This substantially increases the value to a user of building an IDM because of the range of performance analyses that the value can be subsequently performed. Examples of this added value are:

- All software uses the same geometry description generated by the ModelBuilder.
- ROVE can animate and fly through the IDM geometry. In addition, the MicroFlo or SunCast results can be superimposed on the 3D geometry.
- SunCast provides shading and insolution information which can be transferred to ESP and it also acts as a pre-simulation tool for RADIANCE.
- MacroFlo provides bulk air flow data which can be used to enhance ESP and MicroFlo.
- ESP is augmented by the air flow model from MacroFlo and solar insolation results from SunCast. The time-series simulation results from ESP are examined by XTRA.
- The same GUI is used for JASMINE and MicroFlo.

- MicroFlo's results can be considerably enhanced when ESP is used to generate boundary conditions.
- Energy heating and cooling loads from ESP or IDEAL are passed to Ergon to accurately calculate running costs

These tools combine to provide an integrated holistic, design and control tool from the detailed design of a buildings design through its operational life. Consequently, the IES<Virtual Environment> provides the designer with a tool to more fully understand the interrelationships between design variables and performance parameters, to then identify potential problem areas, and so implement and test appropriate building, plant and/or control modifications. The resulting design is more energy conscious with better comfort levels attained throughout.

The <Virtual Environment> is tried and tested and its benefits have been proven in terms of:

- Capital and running cost savings
- Ensuring natural ventilation systems work instead of using air conditioning.
- Rectifying or minimising the risk of "Sick Buildings".
- Minimising energy consumption thereby reducing atmospheric pollution and improving and protecting our external environment.

4.9 The Future of IES

Performance assessment tools have not yet achieved the same market penetration as CAD systems principally because they are labour intensive and time consuming and as such have been difficult to incorporate into the traditional design process. However, performance based simulation will emerge over the next few years to have a more significant role in the design of buildings than CAD systems. CAD companies such as Autodesk and Bentley are developing their object oriented technologies to produce the next generation of CAD systems and they realise that simulation technology is required to add value to their new technology.

IES intend to continue to implement their concept for the <Virtual Environment> and make the necessary connections to current and emerging CAD technology. The complete IES<Virtual

Environment> system will consist of a CAD system, design calculation tools and dynamic simulation software tools.

With subsequent developments involving simulation based systems involving IES technology and facilities management features IES will be able to achieve their objective of providing a system which will be a complete building life-cycle system. This technology will radically improve the quality of the built environment and reduce global warming by helping minimise the production of CO_2 and preserving our fossil fuels for future generations.

From the detailed investigation into IES's suite of computer software, their suite of software while advanced and is of a very high standard technically, is incomplete. They have software that is capable of dealing with all aspects of the mechanical and electrical design process from detailed design to commissioning, apart from however the early design stage. It is the author's opinion that an Early Design Program would be "the icing on the cake" in terms of making their software complete from a building services design perspective.

Chapter Five: Case Studies

5.1 Introduction

The purpose of this chapter is to investigate two case studies. The main objective is to highlight the benefits that designing with dynamic simulation based programs has over the conventional steady state method. Not only will the benefits from a design perspective point of view be established, it is also hoped to suggest possible improvements that can be made to dynamic simulation programs, especially from an early design stage point of view.

5.2 Case Study No. 1 ~ Airport Terminal Development

5.2.1 Introduction to Case Study No. 1

The purpose of this case study is to highlight the benefits that computer modelling and simulation brings to the design process and the energy and environmental savings, which potentially result. During the course interviews with the mechanical services consultants, this particular project was mentioned by a consulting engineer as one of particular interest. As it was possible to receive large quantities of information, the progress of the building from design team appointment through to design decisions and simulations carried out are included in the body of this chapter.

5.2.2 Design Team Appointment

Applications for the proposed extension to the passenger airport terminal were advertised in the European Journal and in the national press for building consulting services.

Several appointments were made for the position mechanical, electrical and structural consulting engineers, architect and quantity surveyors. A short list was drawn up based upon the relevant experience and workload of those whom submitted interest in the project and the client and its own in-house technical consultants interviewed all these. Following the interviews the design team was selected.

5.2.3 Schedule Of Accommodation / Brief

The project consisted of a two-storey extension to the existing arrival terminal to accommodate a new departure hall on the ground floor and restaurant, bar, kitchen on the mezzanine level and retail and toilet cores on the ground and first floor. A new viewing area was also to be included on the roof of the pier building. The total floor area of the extension was approximately 9,300 m2. The project also included refurbishment work on the existing terminal for the purpose of fire safety, refurbishment of arrivals and duty free areas and the reorganisation of the existing basement baggage make-up area to incorporate outgoing luggage. The construction was programmed over a two-year period.

The estimated budget for the project was as follows: -

	£IR
1) new building works (include. mechanical and electrical	13.3m
2) equipment	2.1
3) works to existing terminal	1.7m
Total	17.1m

The mechanical and electrical consultants were expected to attend all design and co-ordination meetings prior to tender, and to make all necessary site visits at construction stage (in addition to regular site meetings) to ensure the correct installation of the Mechanical and Electrical system. The mechanical and electrical consultant was expected to develop a detailed brief in consultation with client and design team.

The mechanical and electrical installation included for the integration of the new installations with the existing in the adjoining terminal building, including any modifications to the existing to facilitate to the new installation. A detailed survey of the services of soils and wastes, gas distribution systems, upgrading high tension and low tension electricity network, baggage handling system, lift and escalators.

5.2.4 Design Process

The manner in which the mechanical service consultants approached the design of the project was investigated. The building was to be designed on the basis of a high quality, low energy and efficient building. The main area of interest in the building was the departure hall. The departure hall can be broken down in to two sections:

1. A 70m long x 14 m wide street with an average height of 14m,

2. A 70m long by 25m wide x 10m high main check-in area

In order to design the building based upon this criteria, accurate heating and cooling loads must be accessed. The mechanical service consultants initially designed the building using the CIBSE method. Again, the heating and cooling loads in the departure area being the main interest of this study.

5.2.5 CIBSE Method

The mechanical services consulting engineers used the standard CIBSE method to calculate the heating and cooling loads. Therefore the loads were based upon isolated extreme values of external summer and winter temperatures. Rule of thumb figures were used initially to estimate the plant loads. They were as follows;

<u>Cooling Load</u>

Lighting gain @ 25 W/m^2
Occupancy gains @ 125 W Sensible per person with a total occupancy figure of 1800 people.
Equipment gain @ 35 W/m^2
Solar gain @ 20 W/m^2
Fabric gain @ 25 W/m^2
Infiltration gain @ 15 W/m^2

This totalled to approximately 500KW

Heating Load

Fabric loss @ 25 W/m^2
Infiltration loss @ 25 W/m^2

Total 50 W/m^2

However, it is standard practice to add margins to this load to estimate the boiler load.

Heating load 50W/m^2
Pipe losses @ 5%
Safety Factor @ 10%
Warm Up load @ 20%
AHU load @ 12%
HWS load @ 10%

The overall CIBSE heating load calculated as 350 KW.

5.2.6 Initial HVAC System Selection

The design brief was very specific in the demands on the mechanical service team to produce an environmental efficient and low energy design. It was therefore decided by the mechanical services consulting engineers to use a displacement ventilation system in the departure hall. With a displacement ventilation system, it was felt that the load demand could be best achieved while providing clean fresh air into the occupied space and also removing all heat gains and polluted air at high level. Free cooling could also be utilised for a large proportion of the year, as the supply air temperature using a displacement ventilation system is well above that of a conventional system, approximately 17 to 20 ^{O}C. A displacement ventilation system works most effectively with high ceilings, which enables stratified air to rise causing higher extract temperatures. This higher temperature enables for lower quantities of supply air required, which therefore results in smaller plant and ducts and reduced running loads. The client accepted the concept and the design of the system began between the engineers and the architect.

One consequence with using a displacement ventilation system is the large amount of diffusers space taken up as the supply velocity has to be very low, in the range of 0.1 to 0.25 m/s, as the air is supplied at low level. Using the cooling load of 500KW, a flow rate to meet this load was $32m^3/s$ of air. However, a huge amount of the departure hall wall area, approximately 75% of the available free wall area, was required as a diffuser with a height of 1500mm. This was obviously unacceptable to the architects.

The mechanical services engineer felt that the heating and cooling loads were over estimated. It was decided to evaluate the loads in the departure hall using a thermal simulation program, partially so not to have to re-evaluate another method of providing air conditioning and partially due to experience on the part of the engineering team that the loads appeared to be somewhat generous.

5.2.7 Thermal Simulation

The design team especially the Mechanical Services Consultants recognised that an advanced thermal and macroscopic air flow simulation was required to establish more accurately the heating and cooling loads, while identifying the occupancy comfort throughout varied season and time modes.

The mechanical services consultants introduced simulation consultants into the design process. The dynamic thermal simulation was carried out using ESP and the bulk air flow simulation by a program called Macroflo.

The departure hall environmental and plant conditions were examined dynamically. One particular advantage over the steady state approach is that all weather variables are included in the calculations, rather than isolated extreme values.

The gains and losses within the space were examined dynamically over the full heating and cooling seasons, while also examining autumn and spring conditions. Comfort levels were checked to determine the levels of satisfaction among the passengers and staff throughout the various seasons.

The effect of varying plant capacity and pre-heat time was examined to determine the most optimum plant control regime and the effects on the departure hall of different plant start times.

5.2.8 Simulation Methodology

The overall objective of the modelling exercise was to confirm the air quantities required to be supplied to the departures hall to maintain comfort conditions during summer and winter.

A peak summer month was simulated to access the performance of the system under stressed conditions. A peak winter month was simulated to access the need for heating in the space. A mid-season month was simulated to access the occurrence of changeover from heating to cooling required.

The first simulations carried out were to access the adequacy of the initial plant size during peak operating conditions, i.e. 500kW cooling or 32 m^3/s of conditioned. The results of this initial simulation are as follows:

Area	**Month**	**Maximum Value °C**	**Time**	**Date**
Departures Hall	July	23.5	12:45 pm	16th July

Table 5.1: Air Temperature Summary

Area	**Month**	**Time**	**Space Temperature**	**Predicted Persons Dissatisfied**	**Comfort Conditions**
Departures Hall	July	12:45	23.5 °C	12%	Slightly Warm, Acceptable

Table 5.2: Comfort Criteria

The overall results verified that a cooling load of 500kW and flow rate of $32m^3/s$ was indeed over sized. The simulation calculated a cooling load of 270kW, a reduction of 46% of the steady state calculation. This cooling load was equivalent to a flow rate of $16m^3/s$. The next step was to run another simulation with this revised flow rate of $16m^3/s$ to establish whether this load will be capable of dealing with the cooling load and estimate the occupancy comfort criteria.

5.2.9 Results

The results of the simulations with the revised flow rates are indicated in the following tables.

Summer Season

Area	Month	Maximum Value °C	Time	Date
Departures Hall	July	25.0	14:45 pm	16th July

Table 5.3: Air Temperature Summary

Area	Month	Maximum Load	Time	Date
Departures Hall	July	270.0 kW	14:45 pm	16th July

Table 5.4: Cooling Load Summary

Area	Month	Time	Space Temperature	Relative Humidity	Predicted Persons Dissatisfied	Comfort Conditions
Departures Hall	July	14:45	25.0 °C	53%	21%	Slightly Warm, Acceptable

Table 5.5: Comfort Criteria

The above comfort criteria is based upon Fanger Comfort Curves and the following information:

- Activity Level = 90.00
- Clothing Level = 0.70
- Air Speed = 0.10 m/s

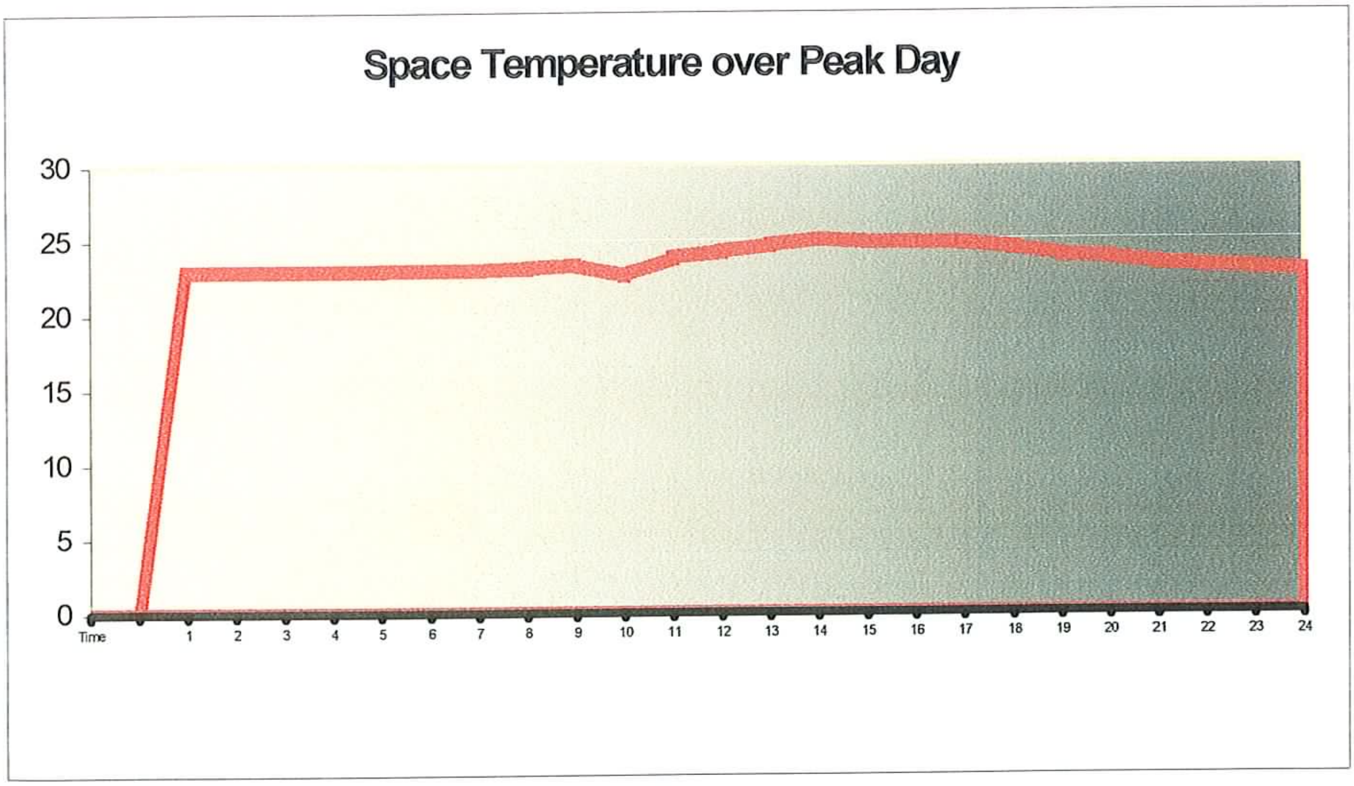

Figure 5.1: Space Temperature in Departures Hall on Peak Day

Mid-Season

Area	Month	Maximum Value °C	Time	Date
Departures Hall	March	23.0	21:45 pm	1st March

Table 5.6: Air Temperature Summary

Area	Month	Maximum Load	Time	Date
Departures Hall	July	100.0 kW	21:45 pm	1st March

Table 5.7: Cooling Load Summary

Area	Month	Maximum Load	Time	Date
Departures Hall	March	150.0 kW	0:45 am	1st March

Table 5.8: Heating Load Summary

Area	Month	Time	Space Temp.	Relative Humidity	Predicted Persons Dissatisfied	Comfort Conditions
Departures Hall	March	0:45	23.0 °C	36%	7%	Comfortable, Warm, Pleasant.

Table 5.9: Comfort Criteria

The above comfort criteria is again based upon Fanger Comfort Curves and the following information:

- Activity Level = 90.00
- Clothing Level = 0.70
- Air Speed = 0.10 m/s

Winter Season

The Winter season yielded the following results:-

Area	Month	Maximum Value °C	Time	Date
Departures Hall	December	23.0	15:30 pm	3rd December

Table 5.10: Air Temperature Summary

Area	Month	Maximum Load	Time	Date
Departures Hall	December	21.0 kW	15:30 pm	3rd December

Table 5.11: Cooling Load Summary

Area	Month	Maximum Load	Time	Date
Departures Hall	December	210.0 kW	0.00 am	1st December

Table 5.12: Heating Load Summary

Area	Month	Time	Space Temperature	Relative Humidity	Predicted Persons Dissatisfied	Comfort Conditions
Departures Hall	Dec	11:30	20.0 °C	36%	6%	Comfortable, Pleasant

Table 5.13: Comfort Criteria

The above comfort criteria is based upon Fanger Comfort Curves and the following information:

- Activity Level = 90.00
- Clothing Level = 0.70
- Air Speed = 0.10 m/s

5.2.10 Simulation Analysis

Summer Season

The initial flow rate simulations kept the temperature at the design condition in the summer of 23^{O}C. However, with the revised flow rates, the air temperature is no longer being controlled at 23^{O}C. Instead the temperature rises above the set point temperature. Nevertheless, the air temperature never exceeds 25^{O}C for a considerable time. This has a number of consequences. Firstly, it reduces energy consumption as the temperature difference between the room air and supply air is greater, hence more cooling can be done with less air. Secondly, the comfort within the space is effected, examining Table 5 shows that the Percentage Persons Dissatisfied of 20 % occurs at peak times. This is quite acceptable from the point of view that these conditions will only happen for a small percentage of time and that the occupants will only be exposed to it for a short time. Therefore their tolerance is higher.

The space temperature does not vary much during the day, indicating that the gains within the departures hall cause the temperature are dependant on the occupancy and casual gains and not on the solar contribution.

Mid-Season

During mid-season times, there is still heating required in the departures hall. Cooling is also required, but only at reduced levels. Information of this kind gives the client valuable insight to the predicted internal space conditions and allows for suitable plant selection and operating parameters.

50Winter Season

During winter, there is little or no heating required during occupied periods and indeed there might be a small cooling load. This is mainly due to the fact that the departures hall is an internal space with only floor and roof exposed to the outside, both of which are highly insulated. Also, 24 hour running of the building and the resulting casual gains go towards offsetting any heat losses which may occur in the space.

5.2.11 Daylighting Simulation

The departures hall is a highly glazed area, with roof lights over the check –in area and glazing over the street area. The picture on the below is a photo-realistic representation of the departures hall. A day-lighting simulation objective was to rationalise the glazing layout and type in order to produce acceptable illuminance levels in the departures hall. It was also intended to establish the glare effects of day-light on area such as passenger monitor screens and advertising boards, using Guth Comfort criteria. The day-lighting program used was RADIANCE.

Figure 5.2: Photo-realistic View of Departures Hall

5.2.12 Daylight Simulation Results

Figure 5.3 on the following page is a plan view of the departures hall taken during June at noon with an over cast sky. (The standard CIE overcast sky is 5000lux). The transmittance of the glazing is 30%. There is clearly a strong contrast between the check-in area and the highly glazed street. The Street level has illuminace levels of over 1000lux, while the check-in area illuminance ranges from less than 50 lux to 350 lux. There is obviously a problem in this area.

Figure 5.4 is taken for the same time and month but for a sunny sky. There is an improvement in the uniformity in this case, with little dull spots.

Figure 5.5 is a day-lighting simulation in June at noon with an overcast sky, but this time the transmittance value of the glazing is 50%. There is a significant improvement in the illuminance levels, hence the day-lighting levels between the two spaces are more uniform.

Figure 5.6 has the same characteristics as Figure 5.5, except with a sunny sky. Again the uniformity is improved in this case.

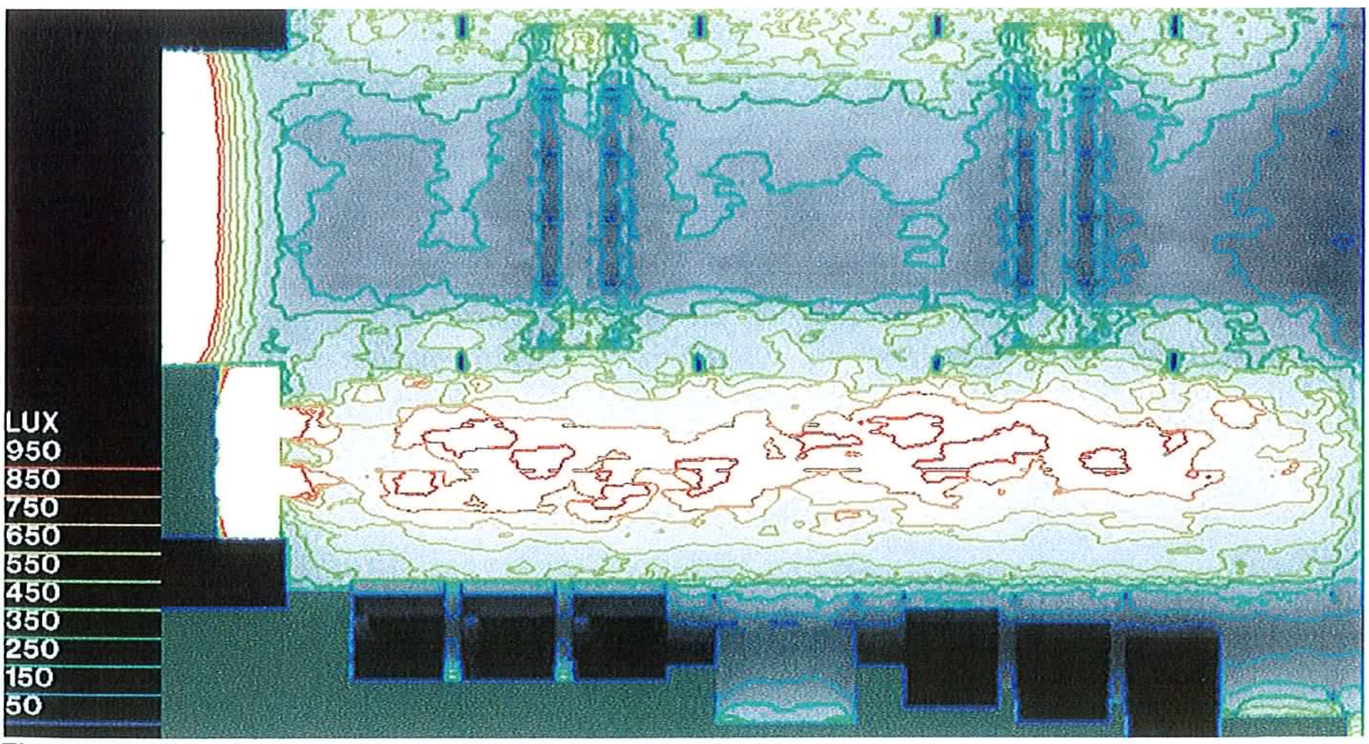

Figure 5.3: June Overcast Sky ~ 30% Transmittance

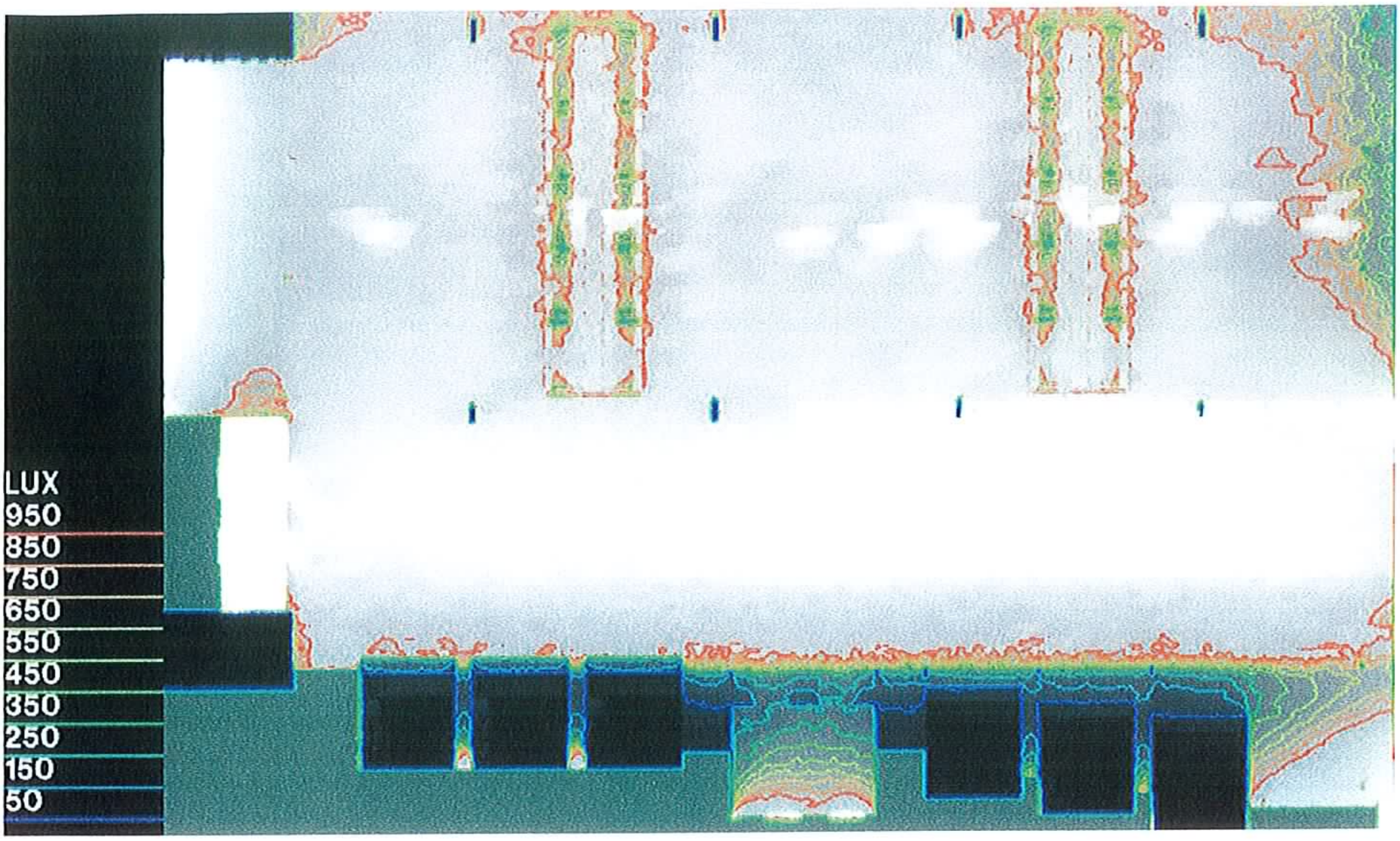

Figure 5.4: June Sunny Sky ~ 30% Transmittance

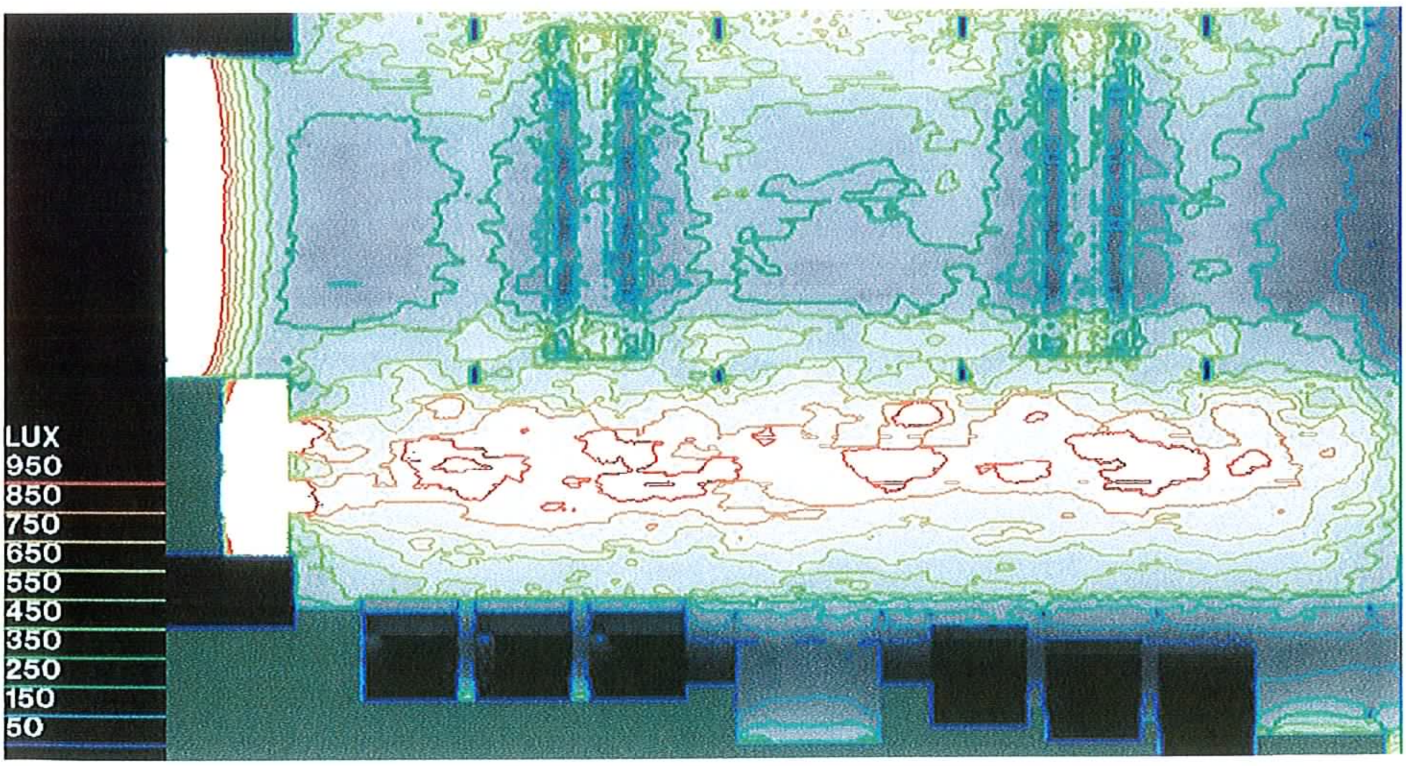

Figure 5.5: June Overcast Sky ~ 50% Transmittance

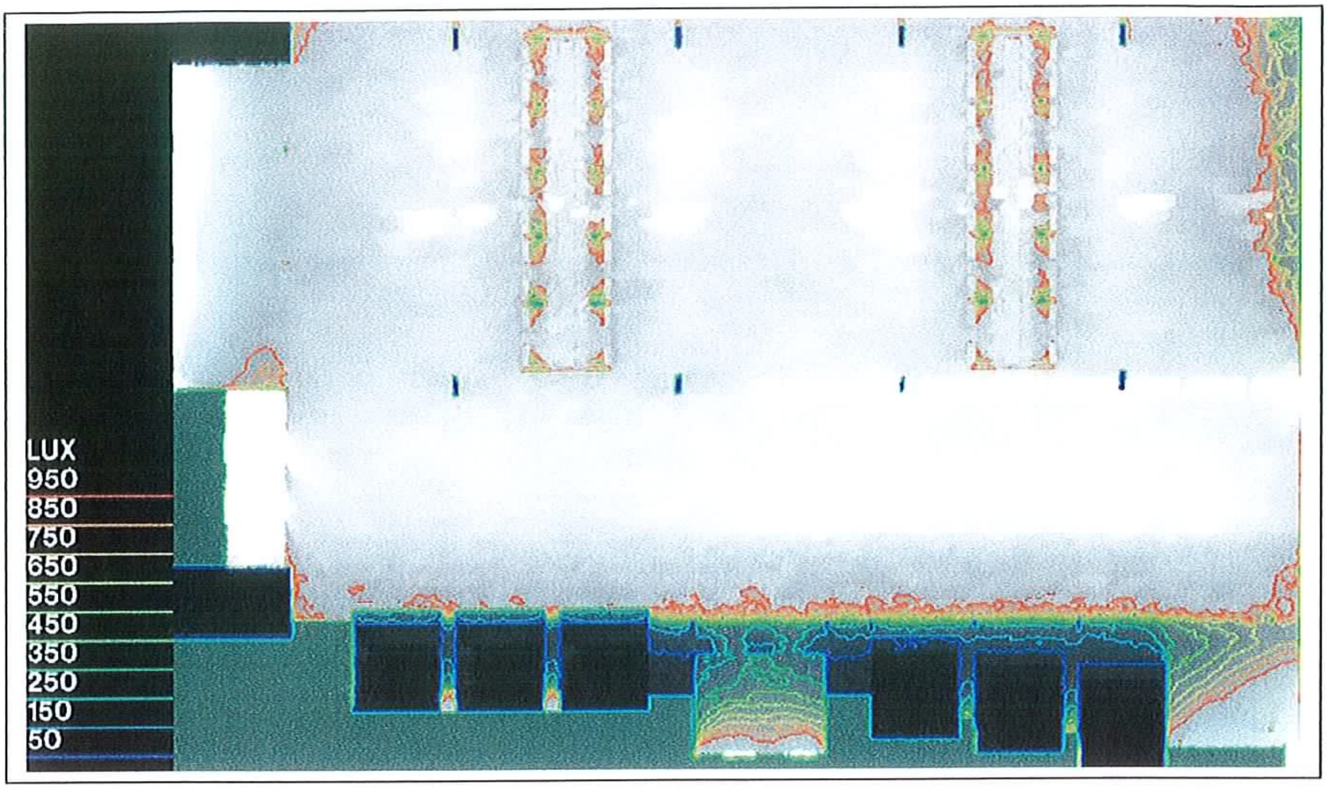

Figure 5.6: June Sunny Sky ~ 50% Transmittance

Figure 5.7 is a Photo-realistic view of the Departures Hall Illuminance Levels taken during September for an OverCast Sky

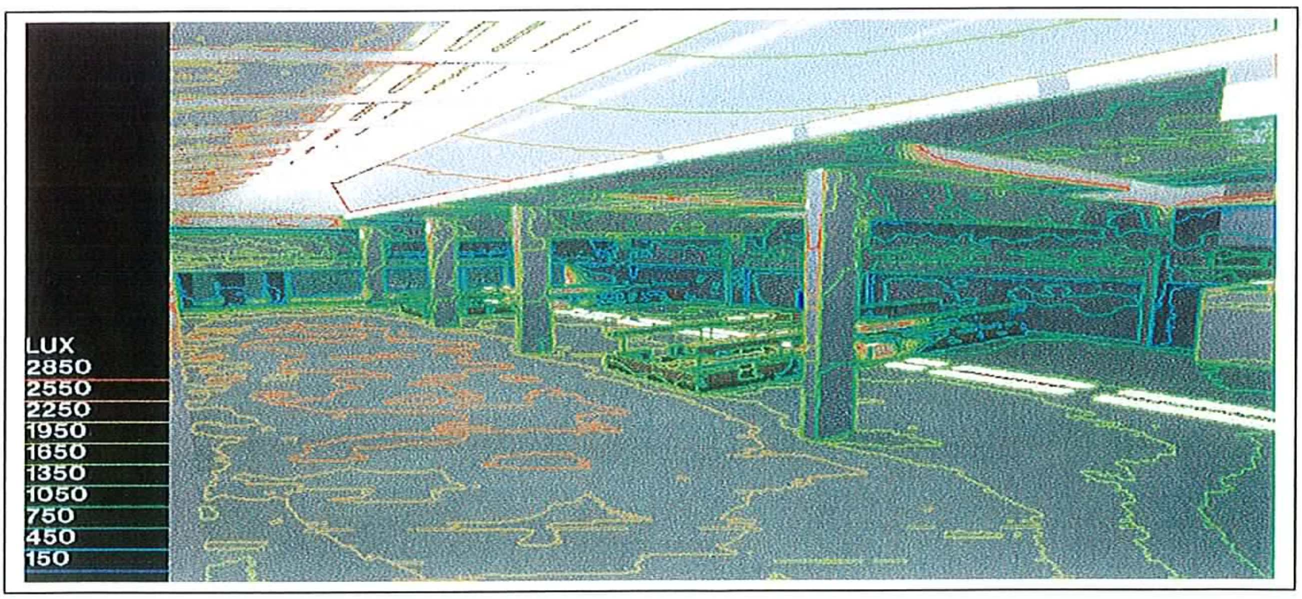

Figure 5.7: Illuminance Levels

The figure below gives a Check-In attendants view and indicates the illuminance levels.

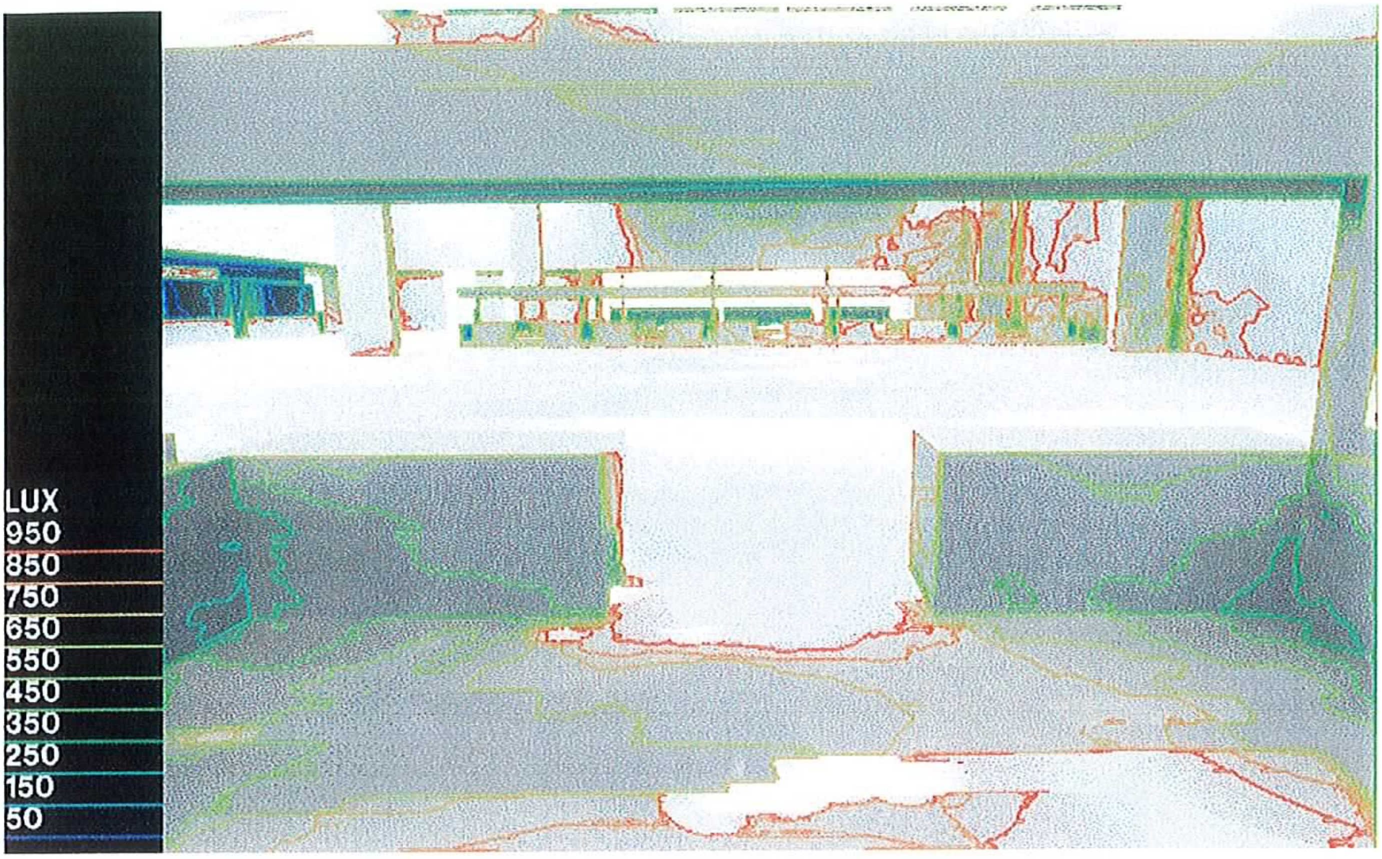

Figure 5.8: Check-In Desks Illuminance Levels

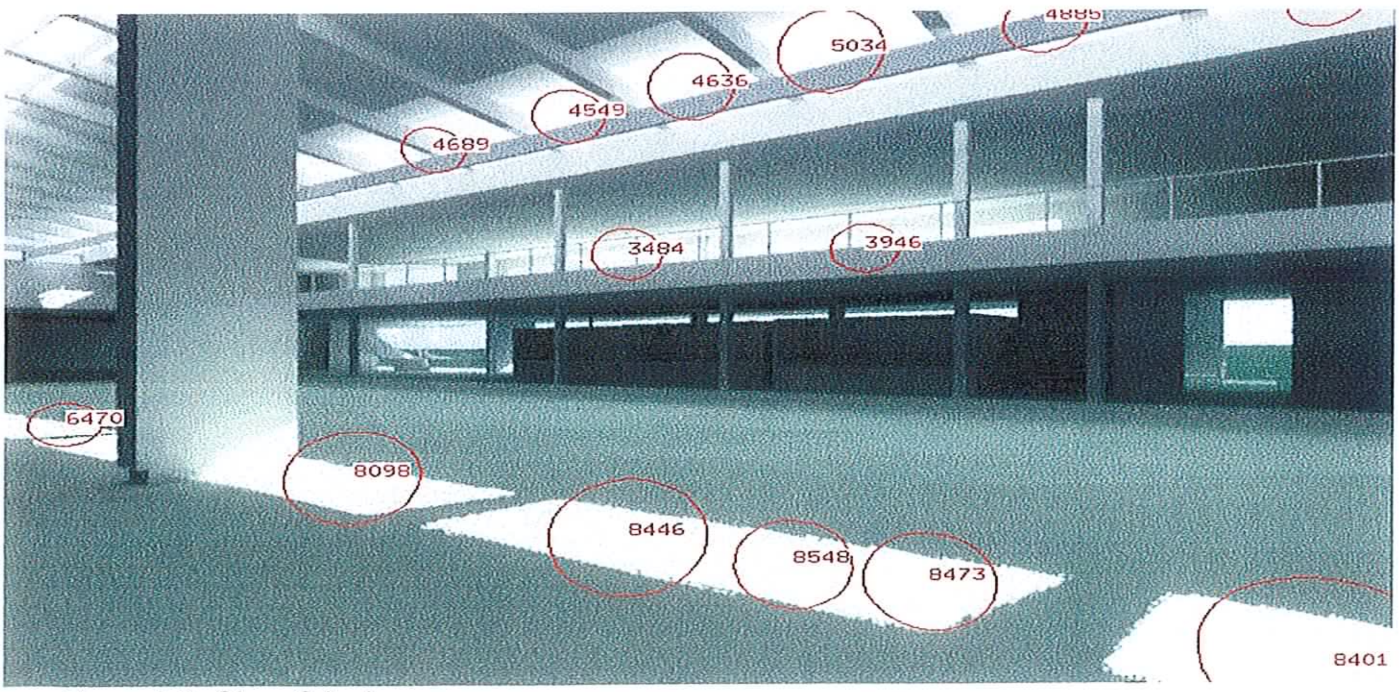

Figure 5.9: Glare Criteria

5.2.13 Case Study No.1 Conclusion

This building's design development has been investigated from the design team appointment through to the thermal and day-lighting simulations. This case study on this airport development is an ideal example of the benefits of using computer simulation modelling brings to the design process. Firstly, with regard to the thermal and macroscopic simulations, the analysis yielded the following conclusions:

- The initial flow rate of $32m^3/s$ of conditioned air was approximately twice as much as the departures hall actually required to maintain the design space temperatures.
- The revised flow rate of $16m^3/s$ conditioned air, although not holding the space temperature at 23^OC was adequate for occupant comfort and reduced the energy requirements for the building.
- The space cooling requirements is very much determined by the levels of casual gains in the space. The benefits of highly insulating the roof can be seen in that there is very little heat loss from the space.
- Little or no heating is required in the space. As the building is in use 19 hours, the need for a heat up period is reduced.

The Day-lighting simulation initially carried out using a transmittance of 30% highlighted that there is not a uniform illuminance level in the departures hall between the Check-In area and the Street. The information from RADIANCE program allowed the design team alter this transmittance factor so that the levels could in improved until there was a more uniform illuminance levels. This procedure and the RADIANCE program aided the design team to maximise the day-lighting in the space creating a more comfortable and efficient space.

It should be noted that normal design methods cannot produce this level of information available to the design team. It is increasing more important to reduce the impact buildings have on the environment. This case study highlights, that simulation programs do indeed aid reduce energy consumption by indentifing accurate heating and cooling loads and maximise natural day-lighting.

5.3 Case Study No.2 ~ New College Development

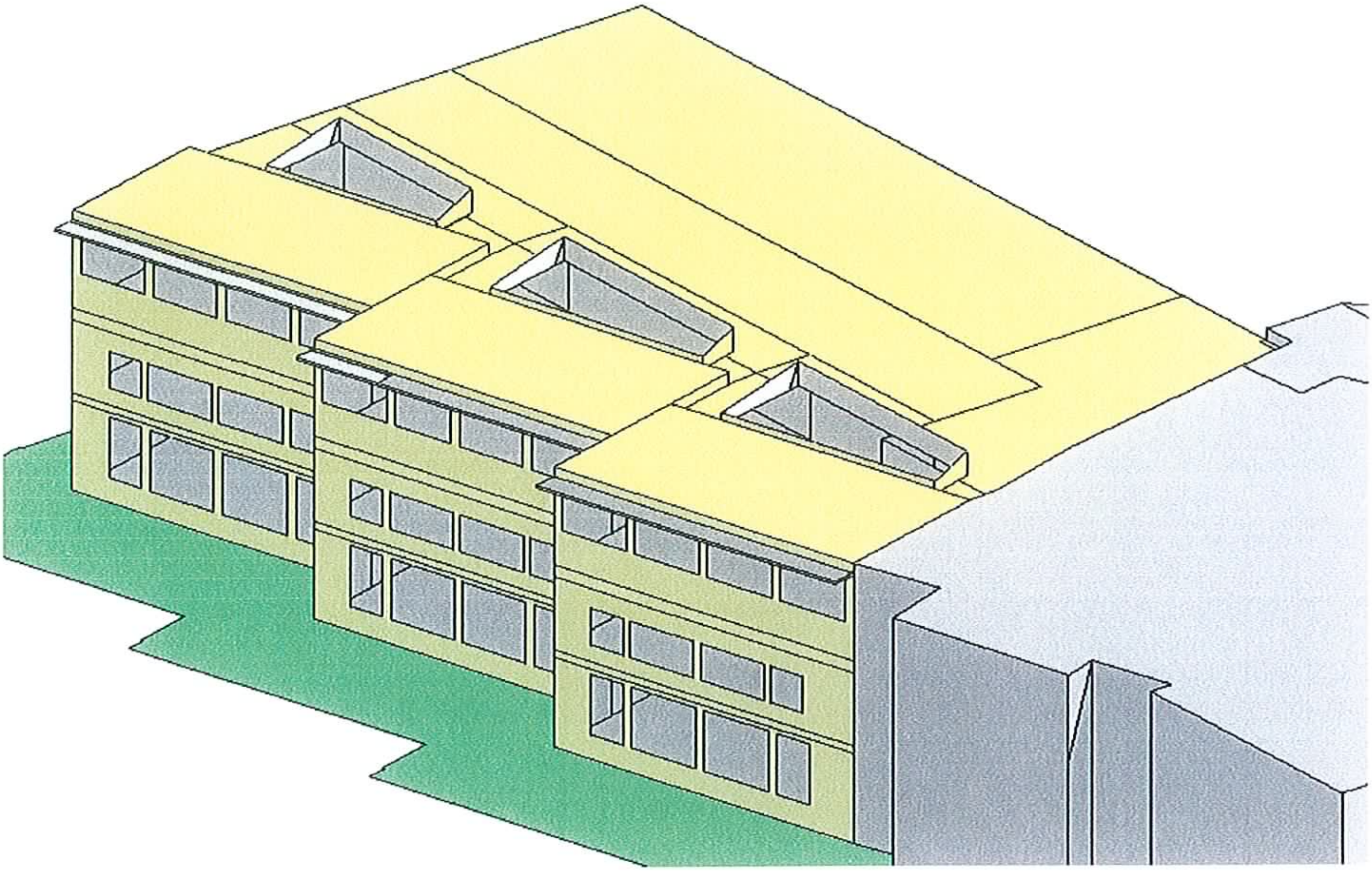

Figure 5.10 Perspective View of Model

5.3.1 Introduction to Case Study No.2

This case study is carried out on an educational building based in Dublin. The building consists of a three storey college development with a total area of 5,000 m^2 providing large lecture rooms, physics and electronic laboratories on the north west face of the building and class rooms, computer rooms and administration offices on the south east block. A large circulation area divided these two faces in which toilet cores, offices are located and also three atriums were incorporated to provide natural daylight to this street area. All laboratories required mechanical ventilation and comfort cooling purely based upon the spaces high occupancy and the nature of laboratories, which often create high heat gains due to experiments and their equipment. The lecture theatres also required some air conditioning, again, which is attributed to the high occupancy and hence fresh air requirement, in which natural ventilation could not guarantee. The classrooms and computer rooms however, located directly next to the atriums, were designed to be naturally ventilated. This initially consisted of the architect and the building services engineer co-ordinating recognised accepted protocol for naturally ventilated buildings, such as a minimum distance of 12 meters for cross ventilation, exposing the slab to absorb heat gains and openable windows and transfer grilles to the atrium. A fire consultant was introduced at an early stage of the design to establish a fire safety design and smoke ventilation requirements.

Based upon the fire consultants calculation for a given smoke load in the atriums, a minimum height for the atriums was calculated in order that the smoke reservoir within the atriums would not be in any of the escape corridors or leak into adjoining areas. Hence the required smoke ventilation sizes were established. Due to the size of the atriums, there was not enough area to extract all the required smoke. Hence three number smoke extract fans were also necessary so that all the smoke could escape during a fire. Fire dampers were required on each transfer grille between the atriums and class rooms and computer room on the ground and first floor and fire and smoke dampers on the top floor.

All of these factors had implications on the success of the natural ventilation system design. The design team brought on board IES at this stage, so that the natural ventilation system could be designed to ensure that all of the architectural and fire consultant's requirements and constraints would be incorporated into providing a successfully naturally ventilated space.

Being an educational facility, it is unlike most buildings in that it is not a year round occupied building. The building occupancy being from September to May, with generally exams in June, therefore high summer time temperatures and high solar loads as not expected. The class rooms and computer rooms are also unlikely to be occupied for prolonged periods, generally not longer than two hours at a time. The occupancy associated is also therefore not a significant as say an office building would be. However, classrooms and computer rooms have a higher occupancy density, usually $5m^2$ per person compared to $10m^2$ per person in an office.

One the main problems was the added resistance across the fire transfers grilles on the ground and first floor and the smoke and fire transfer grilles on the second floor. There was a limited amount of wall area in which could be given over to transfer grilles due to the size of the atriums. Noise from the corridors was also an influence in the amount of area allowable.

The only method of establishing the influence of naturally ventilation on the space and the occupancy comfort profile is to use a dynamic computer simulation, i.e. ESP, SunCast and Macroflo. Unfortunately the full advantages of the IES design team and experience could not be utilised fully as they were employed after planning permission was granted, and therefore room heighs, facade and window designs were already established. Never the less, they were confident that their influence in producing an efficient naturally ventilated space would be extremely valuable.

5.3.2 Dynamic Thermal and Macroscopic Simulation Design Parameters

This section relates primarily to the combined dynamic thermal and macroscopic airflow modelling of the building.

Based on information obtained, the following sub-sections outline the established model.

5.3.3 Climate / Boundary Conditions

The study was carried out using Dublin climatic data.

5.3.4 Model Geometry

The model comprises some 49 zones. A perspective wire frame view of the model is shown in Figure 5.11.

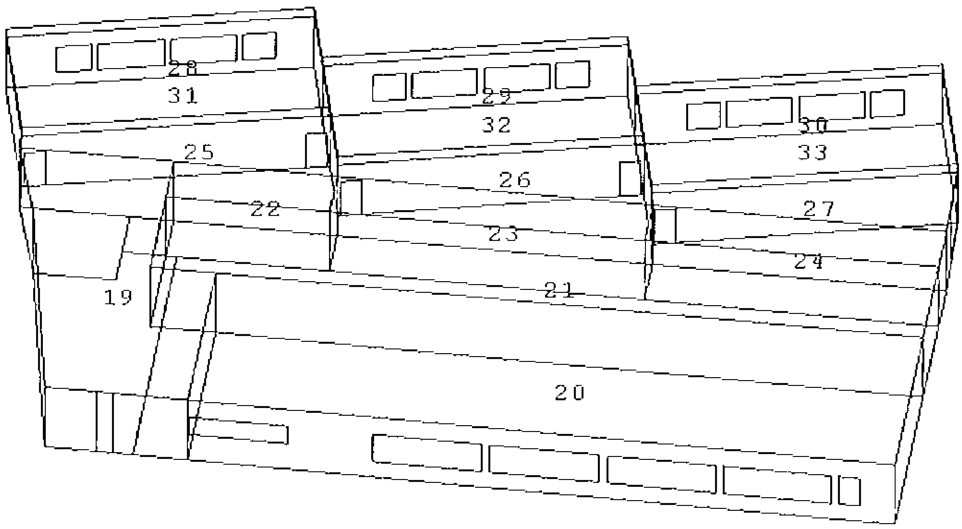

Figure 5.11: Perspective Wiring Frame View of Model

5.3.5 Model Construction

Thermal simulation requires the thermo-physical properties of the building fabric to be accounted for.

5.3.6 Casual Gains

The function and use of the building determine the distribution and variation of casual gains in the building by its occupants and the operation of the services within the building.

5.3.7 Occupancy

As an educational institution, the building is subjected to varying levels of occupancy within a defined time-scale. Occupied hours for the building are from 09.00 to 21.00, Mon-Fri.

Classroom Occupancy Profile:

0.73m^2 /person in the classrooms.
10m^2 /person in the offices.
2.5 m^2 /person in the computer rooms.
40m^2 /person in the transient areas.

It was assumed that all other times no occupants were present.

Each person is assumed to contribute 95W sensible and 45W latent gain to the space. Sensible loads were assumed to be 80% convective in nature, with the remainder radiant.

Lighting:

The peak lighting loads were assumed to be worst case, and are as follows for each of the specific space type:

Classroom: 15 W/m^2, continuous for the full-occupied period.
Office: 15 W/m^2, continuous for the full-occupied period.
Computer room: 15 W/m^2, continuous for the full-occupied period.
Transient: 15 W/m^2, continuous for the full-occupied period.

During unoccupied period the lighting was assumed to be off.

The lighting gain is assumed to be 60% radiant in nature and 40% convective.

Equipment:

Peak equipment loads were assumed to be continuous in space and are quantified as follows:

Classroom: 20 W/m^2
Office: 15 W/m^2
Computer room: 60 W/m^2

During unoccupied periods the equipment is assumed to be off. The equipment gain is assumed to be 50% radiant in nature and 50% convective.

Airflow:

The dynamic distribution and patterns of airflow in the building and its effects are to be analysed. In order to perform a detailed analysis, incorporating full interaction between external pressures and any internal buoyancy and mechanical forces, an airflow network is required to describe the building leakage and flow path characteristics.

5.3.8 Assumptions & Observations

As the building is new, the facade when closed is assumed to be relatively tight in terms of air tightness. Based on data published by BSRIA, a tight building conforms to a leakage characteristic of 5m3/h per m2 of exposed facade (including roof) at a test pressure of 25Pa. In model terms this equates to an open area of 0.034% of the external surface area of each zone.

Permavents have been identified in the external skin of the building and air transfer grilles are used to convey air to/from the atrium. The details of these are as follows: -

Opening Type
Open Area
Permavent 0.5m^2 min free open area
Air transfer grilles 400x400 (50% free open area)
Roof vents 13.47m^2/s

It was assumed that the zones to the south of the atrium are either mechanically ventilated or air conditioned to an ideal control law and therefore have no interaction, except for infiltration through the atrium, to the naturally ventilated Northwest side of the building.

All Northwest rooms are naturally ventilated via openable windows and a permavent connection to the atrium. The windows in the zones will be opened and closed as the space temperature dictates. This is achieved by means of occupant control or a BMS. The control temperatures for these windows are as follows: -

Control Temperature	Percentage Open
20-22°C	10%
22-24°C	25%
>24°C	50%

Ventilation in the atrium is achieved by smoke louvers, which are opened and closed as control zone temperatures dictate.

In order to provide ventilation at times of disadvantageous wind, extract fans in the atrium roof have been identified. The duty of each of these fans is $2m^3/s$ and will activate when the temperature in the computer labs exceeds 25°C.

5.3.9 Building Control Strategy

Summer control conditions fall into two categories, they are as follows:

- Air-conditioned zones: cooling set point of 23°C maximum air temperature and 60% maximum RH
- Naturally ventilated spaces: above 20°C controlled by window and atrium louver opening. Above 24°C controlled by atrium fans.

The air-conditioned spaces will be controlled to an ideal control law. While the naturally ventilated spaces will be controlled to an ideal heating law with a set point of 19°C.

The atrium louvers are controlled from separate temperature sensors in the three ground floor computer rooms. The three atrium fans are also controlled from these spaces. In this way a uniform operation of the fans can be achieved. The control sequence is as follows:

Control Temperature	% Opening
20-22^{O}C	5%
22-24^{o}C	6%
>24^{O}C	100% and fans on

Blind Control

No blinds were identified at this time.

Solar Shading

Shading of the model may come from surrounding buildings and self shading. A solar shading study has been conducted to establish the prevalent solar shading regime for the model. This time series information is later used in the thermal analysis to provide shading and insolation data. A brief graphical summary of this study is presented in Appendix C of this Report.

5.3.10 Simulation Strategy

The client was interested in the thermal performance of the building, with particular regard to the ventilation, and the consequences for fresh air distribution and occupant comfort. The main overall objective of the modelling exercise is to confirm if adequate air movement, considered to be six air changes per hour, can be achieved naturally in the laboratories and classrooms on the Northwest side of the building.

This air movement will be provided from cross ventilation which is induced by both natural means (window and louver opening) and by mechanical means, when internal comfort parameters become unacceptable (rooftop atrium fans).

In order to establish the performance of the building under varying climatic conditions, a peak summer month was modelled i.e. May for an educational institution. This would be used to check the following: -

- Air change rates.
- Air temperature distribution within the buildings, peaks and percentage of time within certain bands were of particular interest.
- Effects of wind and stack pressures on the building.
- Occupant comfort within the spaces.
- The adequacy and control of the extract fans in the atrium roof.

These parameters and more were assessed using two initial simulations with the following scenarios: -

- Natural ventilation only.
- Natural ventilation assisted by mechanical extract in the atrium roof controlled by the ground floor zones.

Based on information generated from these simulations the thermal and airflow design was revised to help reduce the occurrence of peak temperatures, therefore additional simulation was run. The changes were as follows: -

- A decrease in the frequency of occurrence of the casual gains within the classrooms.
- Removal of the air transfer grilles between the modelled second floor zones and the atrium.
- Addition of dedicated roof extract fans in the second floor zones.

It was found that overheating in the second floor zones was still a problem. Therefore one final scenario was simulated with the following changes:

- The dedicated second floor extract fans were removed and replaced with a ceiling mounted cowl with an openable area of $0.5m^2$.
- The second floor computing and classroom zones were removed and replaced with

geometrically identical office spaces.

- The two classroom zones were situated on the first floor alone side one office space.

5.3.11 Case Study No. 2 Simulation Results

Figures 5.12 to 5.16 show results relating to the natural ventilation simulation.
Figure 5.17 show results relating to the atrium fans simulation.
Figures 5.18 to 5.20 show results relating to the dedicated second floor extract fan simulation.
Figure 5.21 to 5.22 show results relating to the second floor cowl simulation

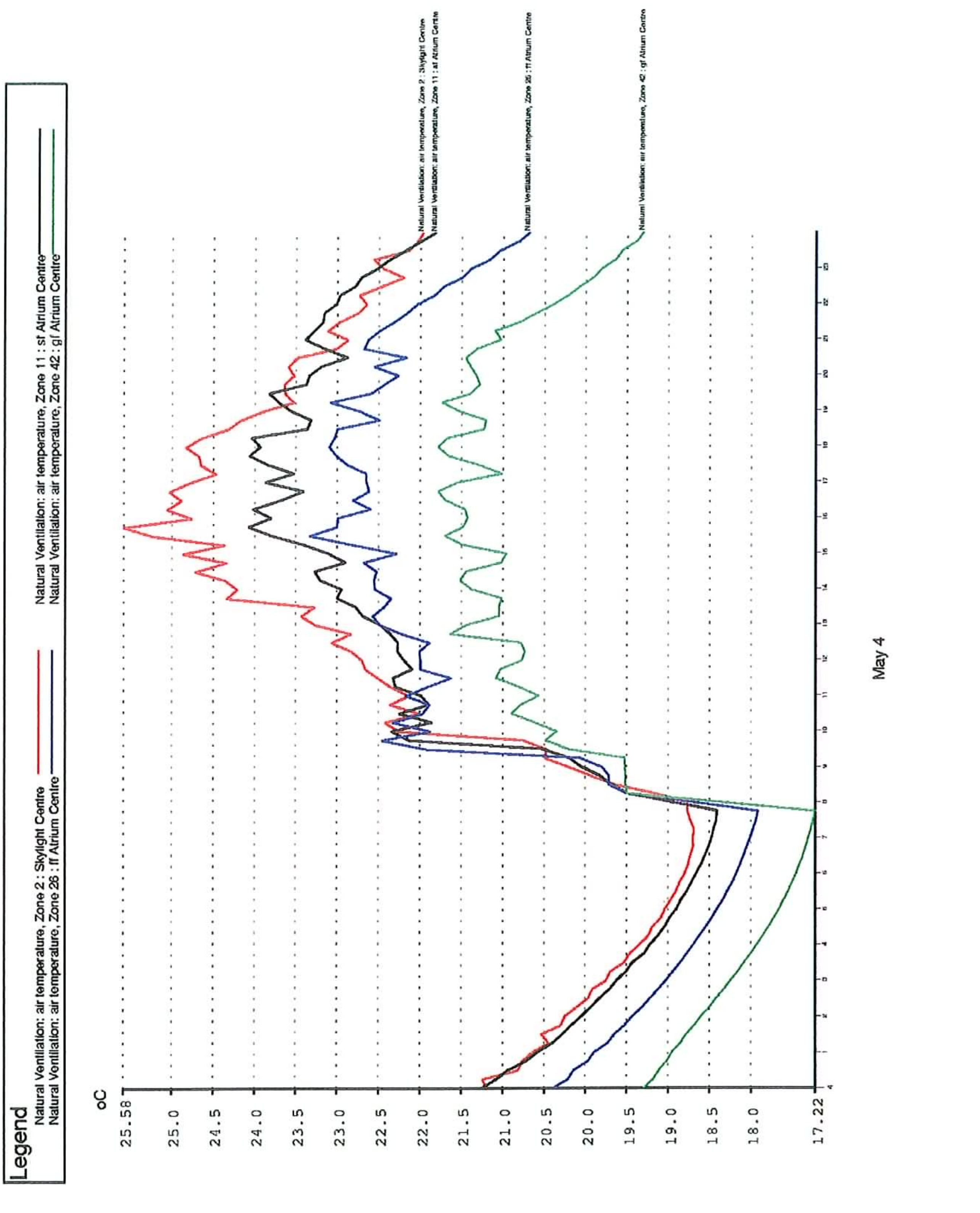

Figure 5.12: Natural Ventilation ~ Atrium Air Temperatures

Result: 12 May 13:07

Layer: 2: Atrium

volume flow rate units = m3/s

temperature = 11.60 oC

wind vel. = 12.90 m/s

wind dir. = 290.00

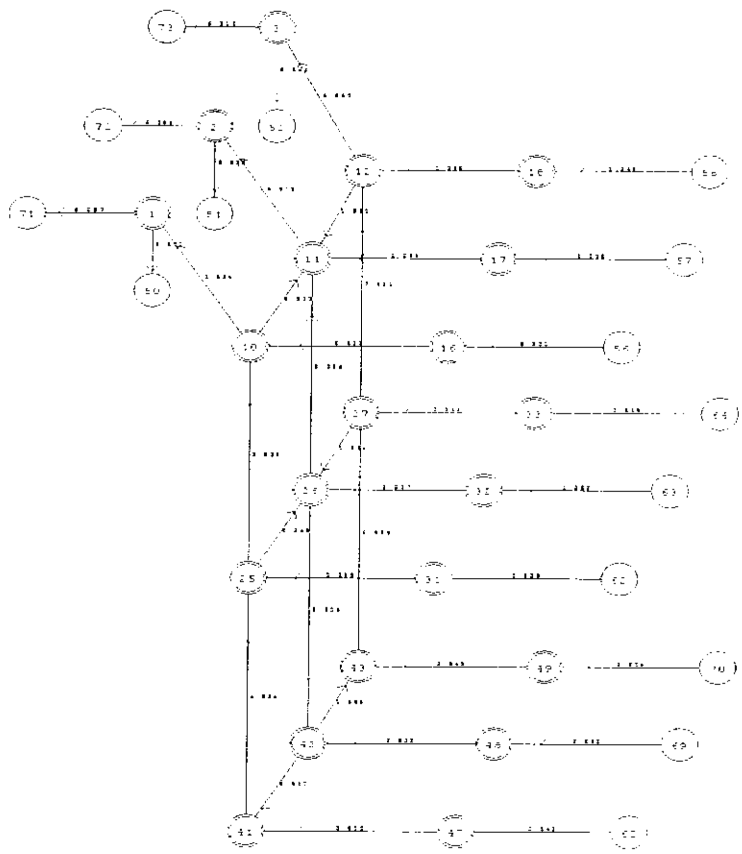

Figure 5.13: Bulk Airflow Distribution ~ Wind Only in Atrium

Dun Laoghaire RTC

Result: 1 May 12:07

Layer: 3: Atrium

volume flow rate units = m3/s

temperature = 15.00 oC

wind vel. = 5.10 m/s

wind dir. = 228.80

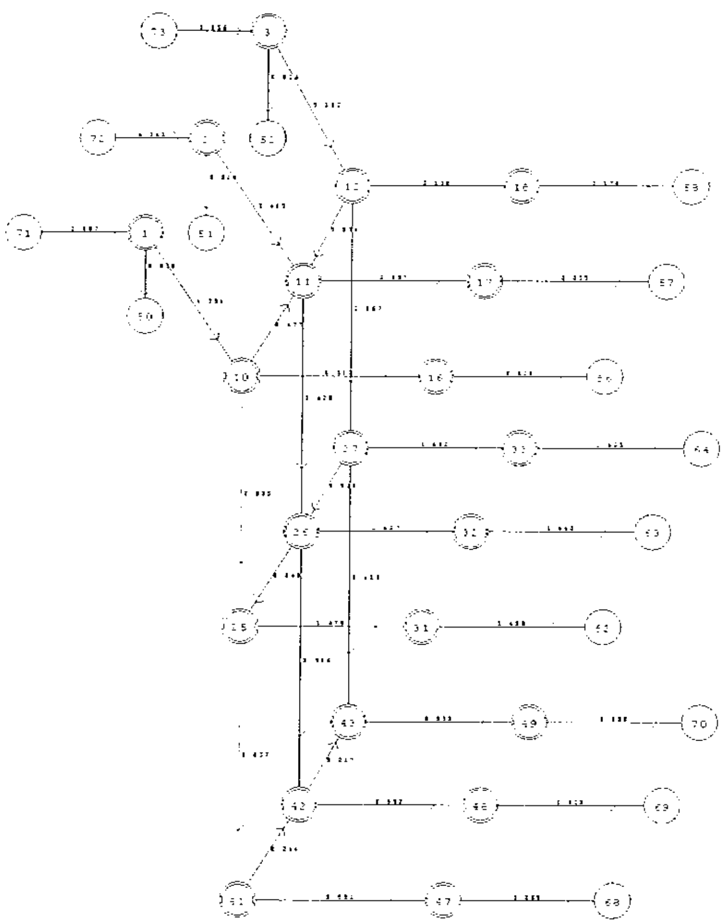

Figure 5.14: Airflow Distribution ~ Wind Only (Atrium)

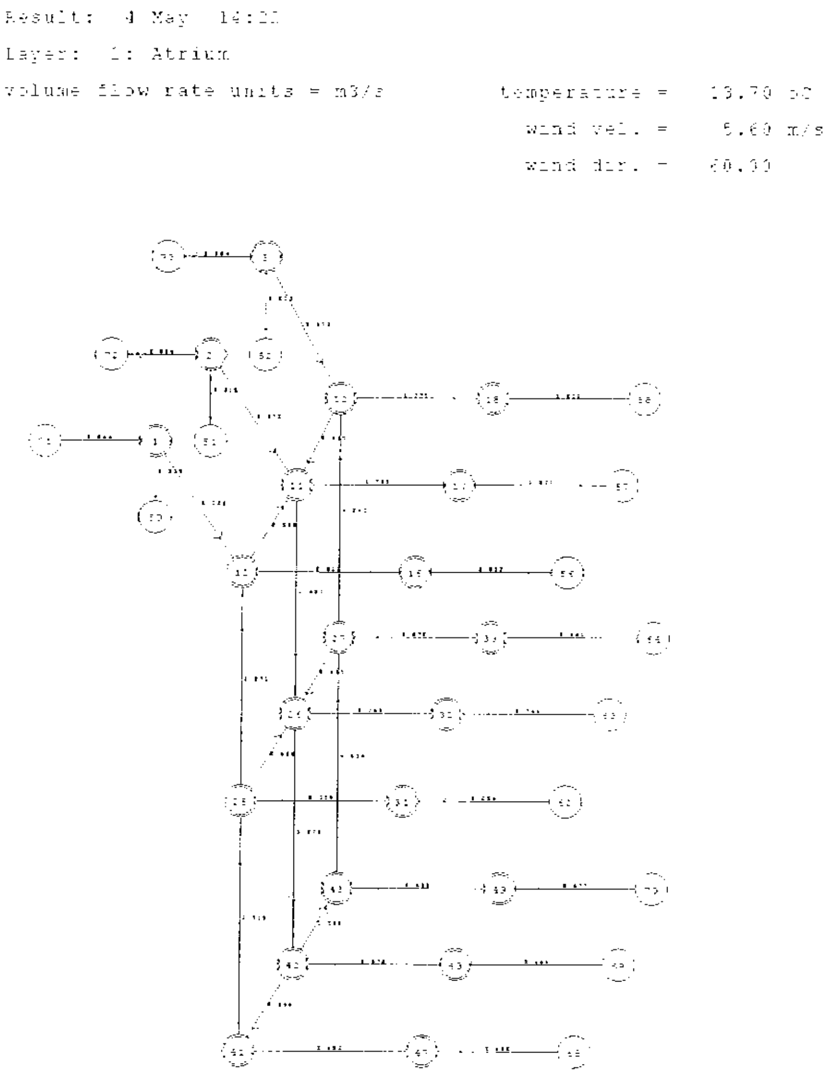

Figure 5.15: Airflow Distribution ~ Stack Only in the Atrium

Result: 9 May 12:07

Layer: 2: Atrium

volume flow rate units = m3/s   temperature = 12.80 oC

wind vel. = 3.10 m/s

wind dir. = 320.00

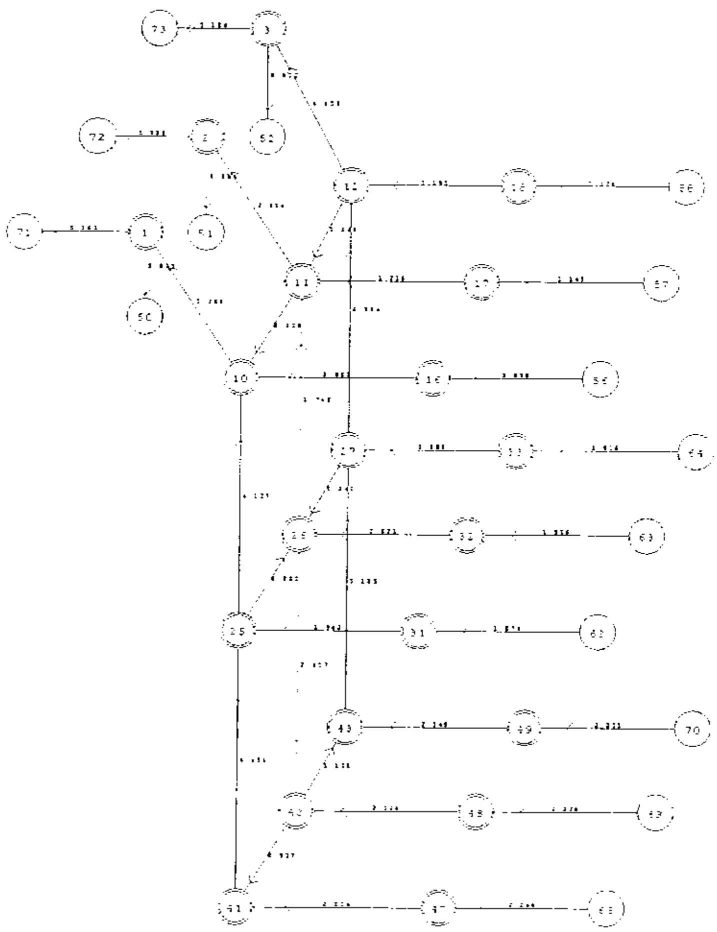

Figure 5.16: Airflow Distribution ~ Wind & Stack In Atrium

```
Result:  1 May  13:07
Layer:  2: Atrium
volume flow rate units = m3/s          temperature =   15.00 oC
                                         wind vel. =    5.10 m/s
                                         wind dir. =  128.80
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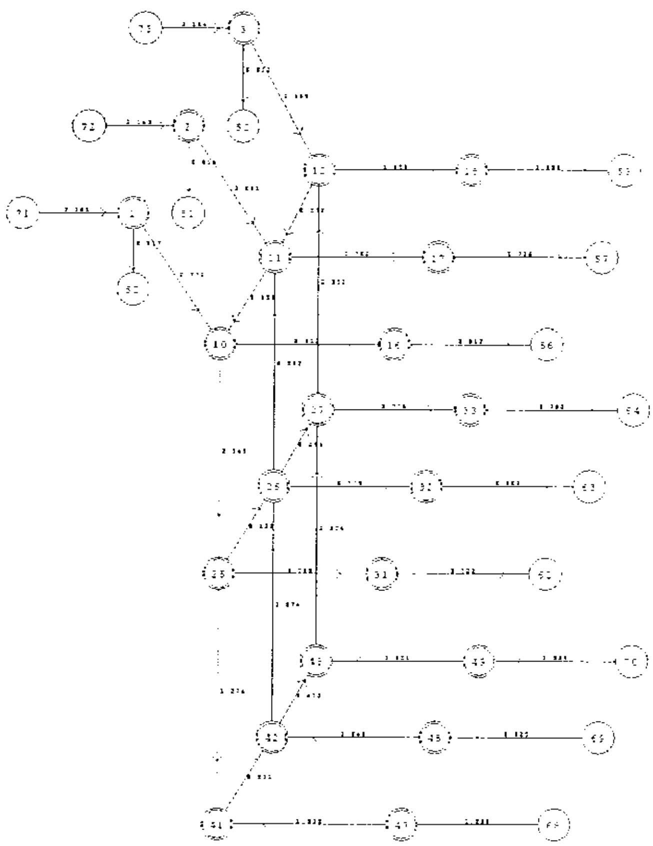


Figure 5.17: Airflow Distribution ~ Atrium

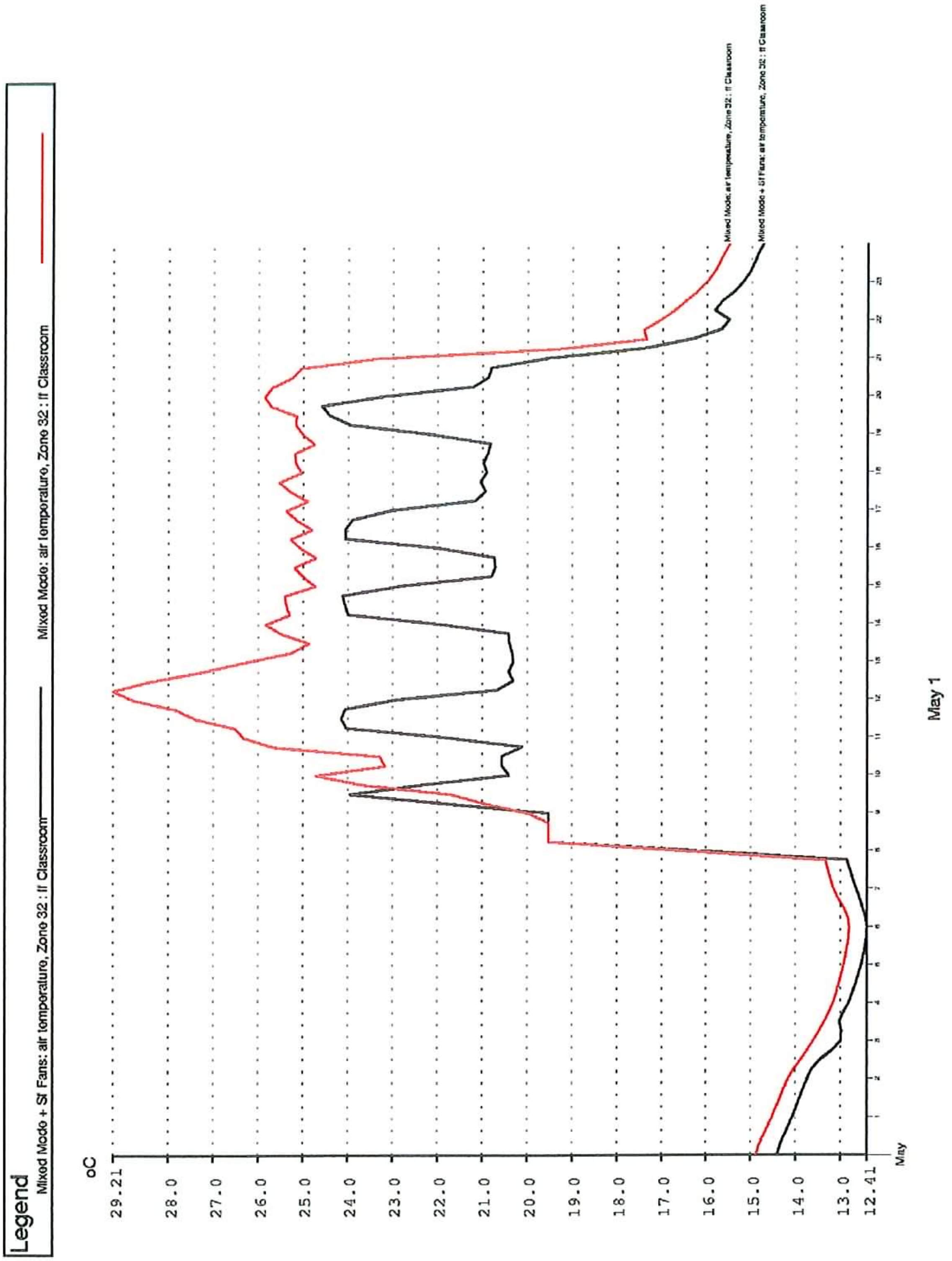


Figure 5.18: Class Room Temperature Profile

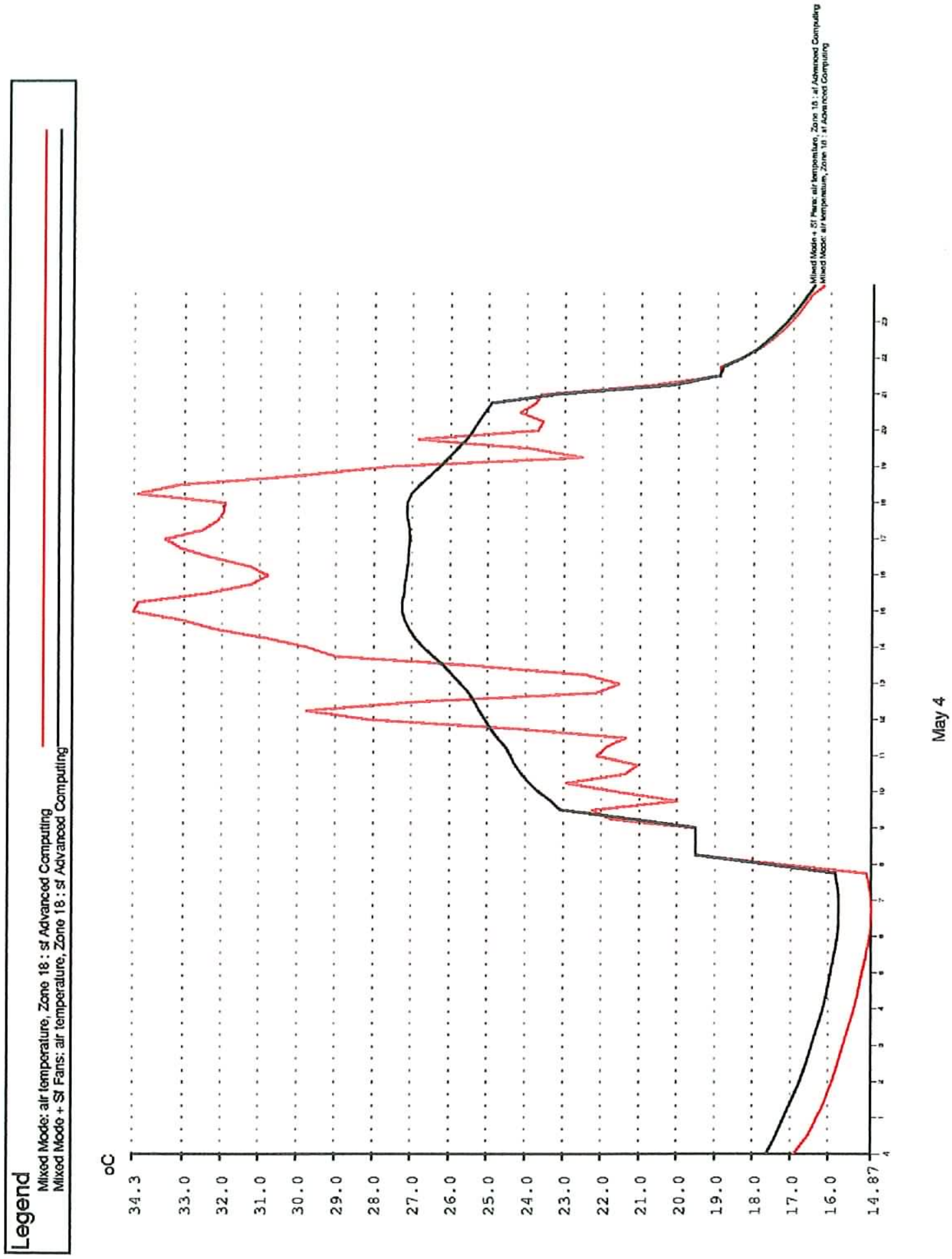


Figure 5.19: Second Floor Temperature Profile

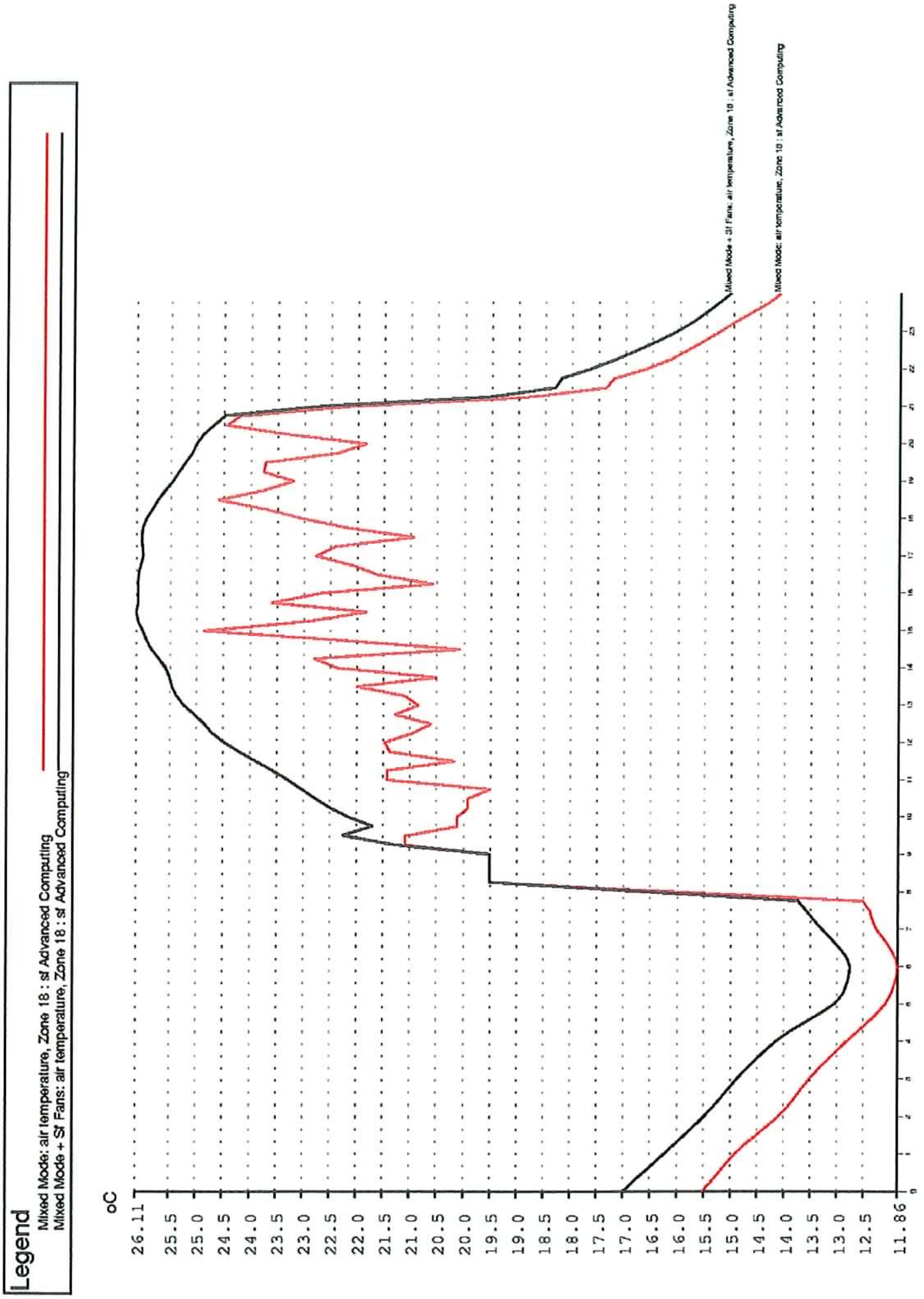


Figure 5.20: Second Floor Temperature Profile with Fans On

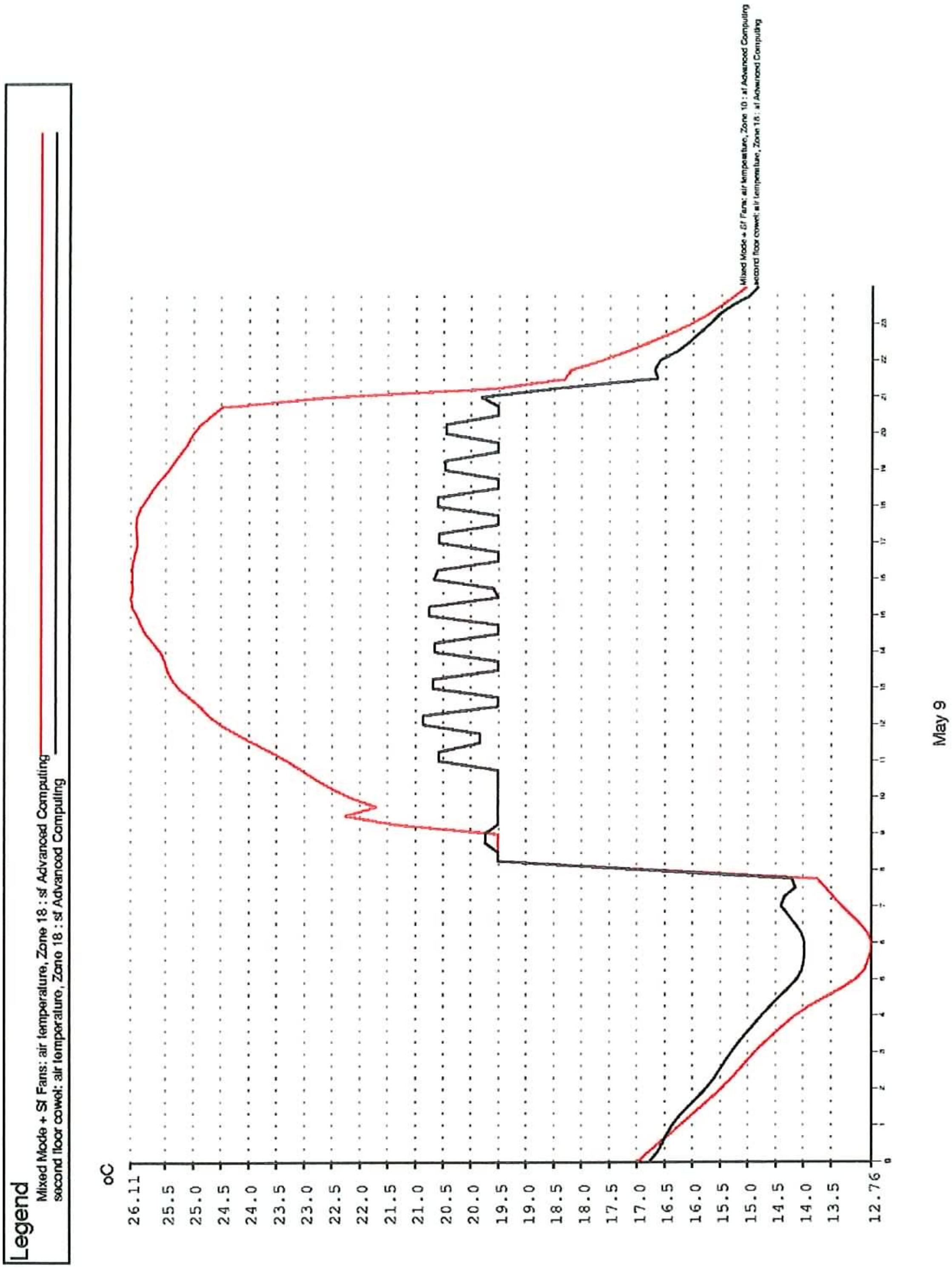


Figure 5.21: Second Floor Temperature Profile with Cowl

Result: 4 May 14:22

Layer: 2: Atrium

volume flow rate units = m3/s

temperature = 13.70 oC

wind vel. = 5.60 m/s

wind dir. = 60.00

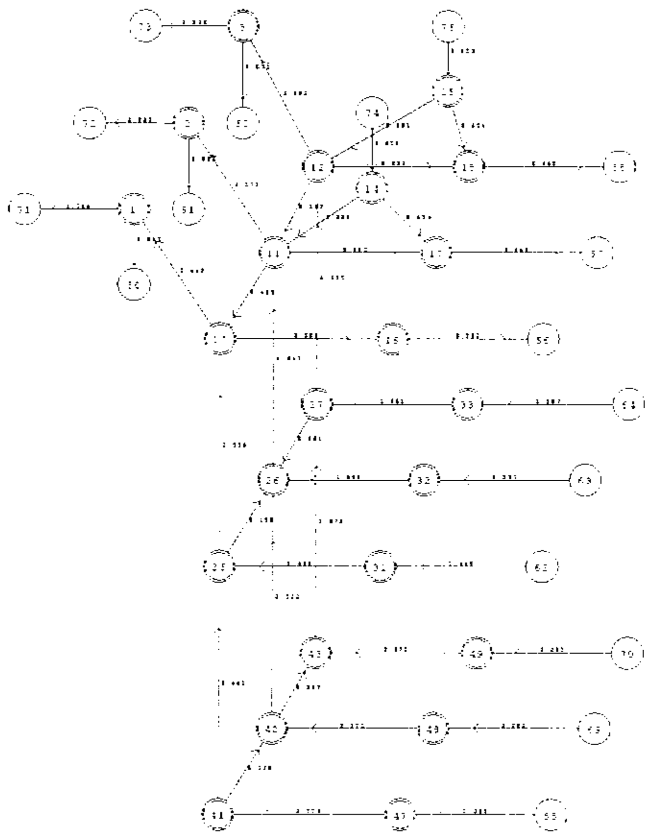


Figure 5.22: Bulk Air Flow Atrium with Fan and Cowl

5.3.12 Analysis of Results

The thermal simulation study revealed a number of interesting issues, which can be summarised as follows:

5.3.12.1 Simulation 1: Natural Ventilation Only:

On examining the natural ventilation results, it can be seen that the atrium stack effect is very strong in this building (Figure 5.12). This is due to the high casual gains in the rooms entering the atrium.

It can also be seen that three very complex 'types' of ventilation occurred at different times, under different conditions. These were mainly influenced by a number of factors but primarily wind speed and direction.

The three different types of ventilation which the building experiences are as follows:-

- 'Stack only' - (Figure 5.15) This occurs when the wind speed is low or from a poor direction i.e. along the axis of the building. In this case the difference in air temperature between the top and bottom of the atrium is great enough to cause a stack pressure which ventilates the ground and first floor well. As the second floor is closest to the top of the atrium, the stack difference is smaller and air is drawn from the atrium to outside. These negative air-changes cause the second floor to overheat considerably.

- 'Wind only' – (Figure 5.13 and Figure 5.14) This occurs when a higher than average wind hits the south side of the building. The positive pressure exerted on the atrium openings and the negative pressure on the north side of the building causes 'reverse' ventilation i.e. air comes in at the atrium roof and leaves via the windows in the rooms. In this case the second floor receives the best ventilation and the ground floor the worst, although conditions on the ground floor are still acceptable.

- 'Wind and Stack' – (Figure 5.16) This occurs when an average or greater than average wind hits the north facade of the building. The air enters via the windows and openings and leaves via the atrium roof due to the combination of wind and stack pressure. This situation is best for the ground and first floor but the second floor still overheats.

It can also be seen that no matter which type of ventilation occurs, the ground floor always stays within an acceptable range. The second floor zones and the first floor classroom on the other hand suffer from the occurrence of extreme temperatures due to their high casual loads and the intake of hot atrium air.

Conditions in the second floor zones are only acceptable when 'wind only' ventilation occurs. This does not occur often (5% of time).

5.3.12.2 Simulation 2: Atrium Fans:

The use of extract fans in the atrium roof, cause a number of changes to the performance of the building:-

- The fans make the biggest difference to the second floor zones.
- As these fans are controlled by the ground floor, the only time they come on is when the ground floor overheats i.e. generally 'wind only' ventilation. This actually has the effect of reducing the amount of air entering the space and the use of these fans is a disadvantage (Figure 6.6).

We can see that the fans are of limited benefit (only on for 2.5% of the time) and the conditions on the second floor, although better, still need further improvement.

5.3.12.3 Simulation 3: Second Floor Sealed from the Atrium with Dedicated Extract Fans:

With the second floor 'sealed' from the atrium and single sided ventilation with mechanical extract in the roof, the following effects were observed:-

- The reduction in the frequency of casual gains within the classrooms substantially reduces the peak temperature occurrence (Figure 5.18).
- The ground and first floors are much the same as in the mixed mode case.
- Although some temperature peaks are reduced in the second floor zones, the conditions are generally worse. Due to the fact that 'wind only' and 'stack and wind' ventilation cannot occur (Figure 5.20).
- Dedicated fans for the second floor rooms is only beneficial when 'stack only' ventilation occurs in the space (Figure 5.19).

From the above it can be seen that the only time cross flow natural ventilation is insufficient in the second floor is when the 'stack only' effect occurs. Therefore to cool the second floor levels adequately it is required to reduce their casual loads (office spaces) and seal them from the atrium. While allowing natural cross ventilation within the space via a cowl in the roof (removing the dedicated fans).

5.3.12.4 Simulation 4: Second floor zones changed to an office environment sealed from the Atrium and provided with a roof cowl:

With the cowl in use, the temperatures within the second floor levels are dramatically reduced (Figure 5.21).

Hot atrium air no longer enters the second floor zones (Figure 5.22)

It can be seen that, when the second floor zones are being cooled naturally by the cowl and the first and ground floor zones are being cooled by the atrium natural air movement and atrium fans (on for 0.8% of the occupied time), acceptable comfort conditions and adequate air movement is achieved in all Northwest facing zones.

The atrium fans, controlled from the three ground floor computer rooms, are not often required and thus the cooling produced in the ground and first floor levels is predominantly natural.

5.3.13 Case Study No. 2 Conclusions

On considering the results of the simulations the following comments can be made:

If the second floor zones are sealed and provided with roof cowls for natural cross ventilation and if the ground and first floor levels are allowed to ventilate via the atrium (final simulation scenario), then the following room conditions should occur:-

- The ground floor spaces, all computer rooms, should be adequately ventilated during the occupied periods by the natural air movement in the atrium and to a small degree the atrium roof fans. This is strongest when 'stack only' conditions occur.

- The first floor spaces, two classrooms and an office space, should again adequately ventilate during occupied periods, by the natural atrium air movement and the roof light atrium fans.

- The second floor zones, two office spaces, should be sealed from the atrium due to the intake of hot atrium air, and thus should be adequately ventilated during the occupied period by natural cross ventilation which is induced by air movement between the window openings and the cowl.

There are several interesting conclusions, which can be established from this particular simulation. Firstly, a significant amount of time, energy and money would have been saved if the dynamic simulation consultant were introduced into the design team at an earlier stage, rather than after the planning permission had been granted, even though the natural ventilation scheme arrived at is adequate, the second floor required to be isolated from the atrium. The brief from the outset called for naturally ventilated classrooms. It was the architect's decision to use three atriums and to locate the atriums and decide upon the geometry of the building. An early design program would have been very important in this project in that several design options could have been investigated and recommendations made to the architect on how the design team could optimise the building design to aid in natural ventilation, day lighting and reduce the energy running costs of the building by suggesting the best geometric layout.

The problems encountered during the simulations could have been avoided had IES an input at the early design stage. The overall design would have been a lot different in design concept layout, while keeping to the parameters of the brief. The atrium for a start would have been a lot bigger in size and capacity and the all classrooms would have utilised natural ventilation. It is the author's opinion that the classroom design would have also been different. The openable window area required would have been specified at this stage.

5.4 Analysis of Case Studies

Two case studies were investigated, both very different in their functions as buildings, both very different in their manner of design and both different when simulation was used during the design process. This was a very useful exercise as it allowed the author to ascertain the type of design information needed for computer simulations. The benefits of using dynamic simulation in the design process and to the design team was very evident and the necessity for simulation in design of buildings became apparent through the advantages in the design process yielding improved design and a quality building in each case. Dynamic simulation was used on these buildings for different reasons in each case.

In the airport simulation, it was a combination between the engineers wishing to establish how the building, especially the Departures Hall, use react and cope with the varying occupancy profiles during different external and internal environmental conditions. The design team hoped to establish the most economic and efficient ventilation strategy and with the aid of using simulation a displacement ventilation system was deemed to be the most efficient. This choice of ventilation proved suitable to cope with the high expected internal temperatures expected during peak occupancy, hence catering for the heat gains, while also providing sufficient fresh air into the space to meet recommended air quantities. The design team was also concerned that in order for the displacement ventilation system to operate to its most economic and efficient capacity, a high temperature at the extract grilles at ceiling level must be achieved. The simulation produced extremely satisfactory results for the design team in that a temperature of 32^{O}C was achieved during peak loads and a overall temperature difference between the supply and return temperature of approximately 15^{O}C. In summary by using computer simulation, the design team engineered a ventilation system that was approximately half the air flow, cooling and heating loads that would of been achieved using CIBSE design methods resulting in an environmentally more efficient designed building.

A lighting simulation proved extremely beneficial to the project. Daylighting in the Departures Hall was maximised producing an overall relative uniform illuminace level between the high glazed roof of the street and the adjacent check-in area. This was achieved by simulating the building with a number of different glazing components until the most efficient type achieved. No other method currently on the market could have produced these answers to this particular problem. High glare areas were identified and the most efficient location of view screens and monitors established as a result, causing as little glare as possible to occupants.

Finally, the last example of computer simulation case study was on a new educational facility. Again, the clients brief described the building as being a low energy building, using natural ventilation and natural daylighting were viable. A viable design solution was in fact achieved through computer simulation. The possible operating problems were identified and the design team was therefore able to rectify these problems before construction took place. This undoubtedly saved long terms operating system problems and indeed further expense to the client. Simulation was unfortunately employed at too late a stage, i.e. after tender stage, in this instance and the full capacity of the atriums could not fully absorbed in the building. An 'Early Design Stage' design study would have been extremely beneficial in this particular building. A simple quick sketch design model could have identified the likely problems much sooner, suggested the optimum layout and location of the atriums, perhaps recommended a larger single atrium, and the client could access the best design solution that met his means while weighing the options from an environmental, cost, running and capital point of view.

5.5 Conclusion

In essence, simulation proved extremely beneficial in both of the case studies, resulting in reduces energy demands and reduced impact on the environment. However, the simulations were carried out at too late a stage in the author's opinion. A lot of engineering time would have been saved had co-ordination of the early design stage information to achieve the brief been carried out initially at a pre-CAD stage. The author believe that further environmental and energy saving benefits would have occurred in each case. The design team would have had a significant amount of information and design options available to them much sooner. Alternative design options could have been investigated quickly and efficiently and the most suitable option decided prior to architectural plans started.

It is the author's opinion that an early design stage computer program in the Airport project would have saved a lot of wasted design time, the CIBSE calculation and initial designed solution would not have occurred. However, a displacement ventilation system would of been arrived at as it would seem to me to be the very suitable in this particular application, utilising the large fresh air requirement and high ceiling heights to produce a lower air flow rate that a conventional dilution system would have required. The author also believe that a thermal and lighting simulation would still be necessary to determine the exact comfort conditions from a temperature and lighting point of view.

Finally, as previously stated, the educational building is an ideal example of how the design brief could be quickly investigated for several different design options, orientation, glazing and structural types and optimum location of the atria.

These are just two case studies of buildings design in the late 1990's in which either an energy efficient client or environmentally conscious design consulting engineer used simulation to arrived at a better quality, lower CO2 emission and reduced energy solution. The importance of increasingly the awareness of clients and design teams to computer simulation cannot be under estimated in the author's opinion. More buildings currently being designed simply must use simulation in order to reduce the adverse impact that building have on the environment and on natural resources such as fossil flues and water. Unfortunately not enough engineers are using simulation. It is the author's opinion that the solution is that an early stage computer program must be developed to identify alternative design solutions or a program in which the comparison between the results obtained from simulation software and the conventional isolated extremes method of design could be examined hence aiding in breaking down the barriers than existing in the design philosophy of many consulting engineers.

Chapter Six: Performance Specification For An Early Stage Computer Program

6.1 Introduction

During the course of this thesis to date, an investigation was carried out on the following to establish the current design engineering market, the design methods and programs available and members of the design team:

- The approach of the design team towards the development of a building,
- The computer programs available on the market for design, research and educational purposes.

Integrated Environmental Solutions (IES) were established as the world leaders in simulation software and consultancy.

A survey of building services engineers was also performed to establish:

- What computer programs are being used to determine building loads,
- Their awareness of alternative design methods,
- Their awareness of computer simulation programs,
- Their awareness of the detrimental effects that buildings and their services have on the environment,
- The need for an Early Design Stage Computer Program.

Two case studies were completed on buildings designed using both thermal dynamic simulations and computational fluid dynamic programs and CIBSE steady state method. These case studies highlighted the benefits that computer simulation programs bring to the design process and the vast quantities of information available to the design team.

Throughout this thesis to date as described above, the need for an early design stage program has been identified. Engineers, architects, clients and the market in general recognise that good design decision-making at the sketch design stage can lead to major benefits in terms of cost and building performance.

The purpose of this chapter therefore is to develop the specification and requirements for an integrated early design stage computer program. This will not only be based upon the input that was received from engineers and architects and the needs of the building services market to improve the quality of buildings and reduce their environmental impact, but also from the knowledge gained from the literature review of simulation programs on the market. detailed discussions with my Industrial partner IES to develop this specification and indeed the computer program based upon the above criteria and also so that the program would have an in-built interoperability between it and IES suites for building services engineering computer software and programs.

6.2 Specification

It has been decided between the author and the industrial partner, IES, to call this early design program IDEAL (Integrated Design Evaluation and Appraisal of Layouts). The specification for IDEAL is as follows:

The computer program shall:

- be a simple to use computer-based 3 dimensional sketch design tool to create computer generated models of buildings,
- be capable of importing AutoCAD drawings,
- be capable of sharing information with other building services engineering performance assessment software in the IES suite of software programs to enable thermal, lighting and air flow analyses and studies.

As it is vitally important to study the thermal properties and performance of the building construction, the construction details shall be defined within the modelling building process. The weather data, site conditions, internal design conditions and internal gains and profiles shall also be created and developed during the model building stage. This will allow optimisation of particular design factors and informed trade-off between competing factors permitting the design team to undertake design analysis, in terms of the constraints imposed by the client's brief and requirements.

The program shall;

- be able to be recognised by an integrated data model and use this data to predict the Building capital.

The program shall have default standard cost planning calculation and presentation form information inherent in the program, which will provide quick answers on cost issues for a standard building. It shall be possible however, to input additional cost information for the building, construction, running, capital and environmental costs to enable analysis of different types of buildings and projects which would come under the non-standard building type.

The cost planning form shall be broken into a number of Categories, each with a number of Elements. Each Element shall be assigned a Code and a Unit Cost. This Code will relate to measured values such as ground floor area, total floor area, number of windows, total area of construction type, and so on. The Elemental cost can then be calculated from the measured IDM value and the Unit cost. This would permit the Category cost to be calculated and subsequently provide an estimate of the capital cost of the Building. Modifications to the integrated data model can then be quickly evaluated in terms of capital cost, or alternative designs compared. This would enable the client or design team to evaluate the building on a number of design levels and options, such as energy performance, capital costs or running costs.

It shall be possible to examine design decisions such as building orientation, percentage of glazing, structural thermal characteristics etc. The program shall have the ability to run all these scenarios and compared them in table form. An analysis can therefore take place to access the benefits of different options from all angles by the client and design team, hence ironing out potential future problems for the design team at an early stage.

The program shall be able to transfer information to Apache-Calc, ESP and Macroflo. This part of the program will enable the analysis of the thermal performance of the building in question. The annual energy consumption for the building, the heating and cooling loads and the mechanical and electrical services electrical duties shall be calculated using these programs. The results shall be transferred and recorded into a file in IDEAL for each individual scenario.

The program shall be capable of calculating the total Running Energy cost of a building based upon the actual running cost data from systems such as heating and ventilation systems. The program shall have in-built default values for pump, fan, boiler, chiller running costs. It shall be possible however to alter these figures for non-standard buildings. The total running costs shall also be a function of the actual running time of each item of mechanical and electrical plant. All information calculated shall be stored in a Running Cost file in IDEAL for each individual scenario run.

The program shall have the ability to calculate the environmental costs of a building. CO2 production and CO from building services plant, NOx from boilers and SO2 emissions shall be calculated based upon the plant duties as determined from the thermal performance calculations and the actual running time of all building services plant. Again, all Environmental costs shall be store in a dedicated file for each scenario in IDEAL for comparison and analyses purposes.

The program shall have a miscellaneous section within IDEAL from which the user can select non standard situations to analyses and investigate. The user shall be capable of inputing this information directly into IDEAL and store it in a separate miscellaneous file.

The program shall be capable of creating scenario folders or files within IDEAL from which modifications may be made to the initial building developed using the model builder. IDEAL shall then calculate all the different parameters for the new scenario and input the new information into new files for each of the relevant sub programs.

All information shall be reading into a Results file for each of the different scenarios and different variables within each scenario calculated. The results file shall create outputs for all different scenarios in percentage figures and actual value difference from the base building.

Scaling and weighting factors shall be assigned to each individual scenario and multiplied by the percentage figures to calculate the best overall building from the design team brief criteria. The scale factor is a positive or negative figure of unity and the weighting factor is a value selected by the user and applied to each variable.

The program shall be capable of being fully integrated to the other IES software in order to enable information to be shared and used at later stages in the design process.

The results shall be user friendly and identified in table format such that various scenarios can be easily analysed and assessed.

Chapter Seven: Application of IDEAL

7.1 Introduction

A Beta version of IDEAL has been developed by IES based upon the specification described in Chapter 6. The purpose of this chapter is to explain in detail the mode of operation of this Beta version of IDEAL.

There are four principal modules associated with the IDEAL system. The following diagram shows the relationship between these four modules.

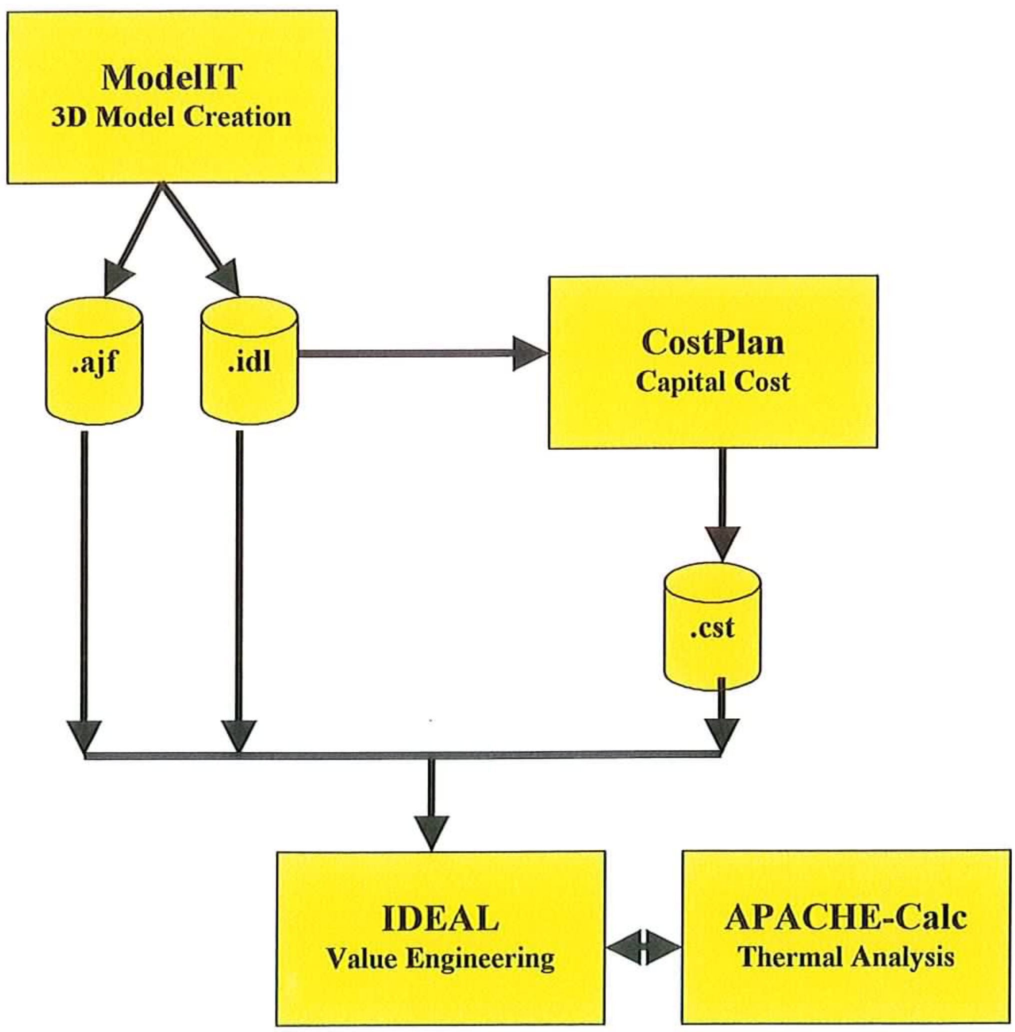


Figure 7.1: Principal modules associated with the IDEAL system

7.2 ModelIT

The first step to create the building model through a sketch program called ModelIT. ModelIT is a graphical 3D building modeling system. ModelIT generates an Integrated Data Model (IDM). The IDM allows for the information of the model to be shared with all other IES Facet software and allows for the following studies to be carried out:

- shadow modeling,
- dynamic thermal simulation,
- multi-zone airflow analyses
- and electric lighting/daylighting studies.

Basically, there are five steps in the ModelIT procedure:

1. Default constructions are defined (e.g. walls, floors, ceilings), along with building defaults (site and weather data) and room defaults (e.g. thermal, lighting, casual gains, air exchange).
2. A 3D-geometry model of the building is created using a number of geometry 'objects' to rapidly build the appropriate 3D geometry. Each object is a zone or room of the building.
3. Windows and doors may be added to any surface of the model, ModelIT automatically distinguishes between windows and roof-lights.
4. Once ModelIT has generated the data model, clicking on an icon accesses the appropriate IES-Facet program such as APACHE (thermal analysis), SHADOW (shading prediction) and FLUCS (lighting design and analysis).
5. The model can be exported in IDEAL format.

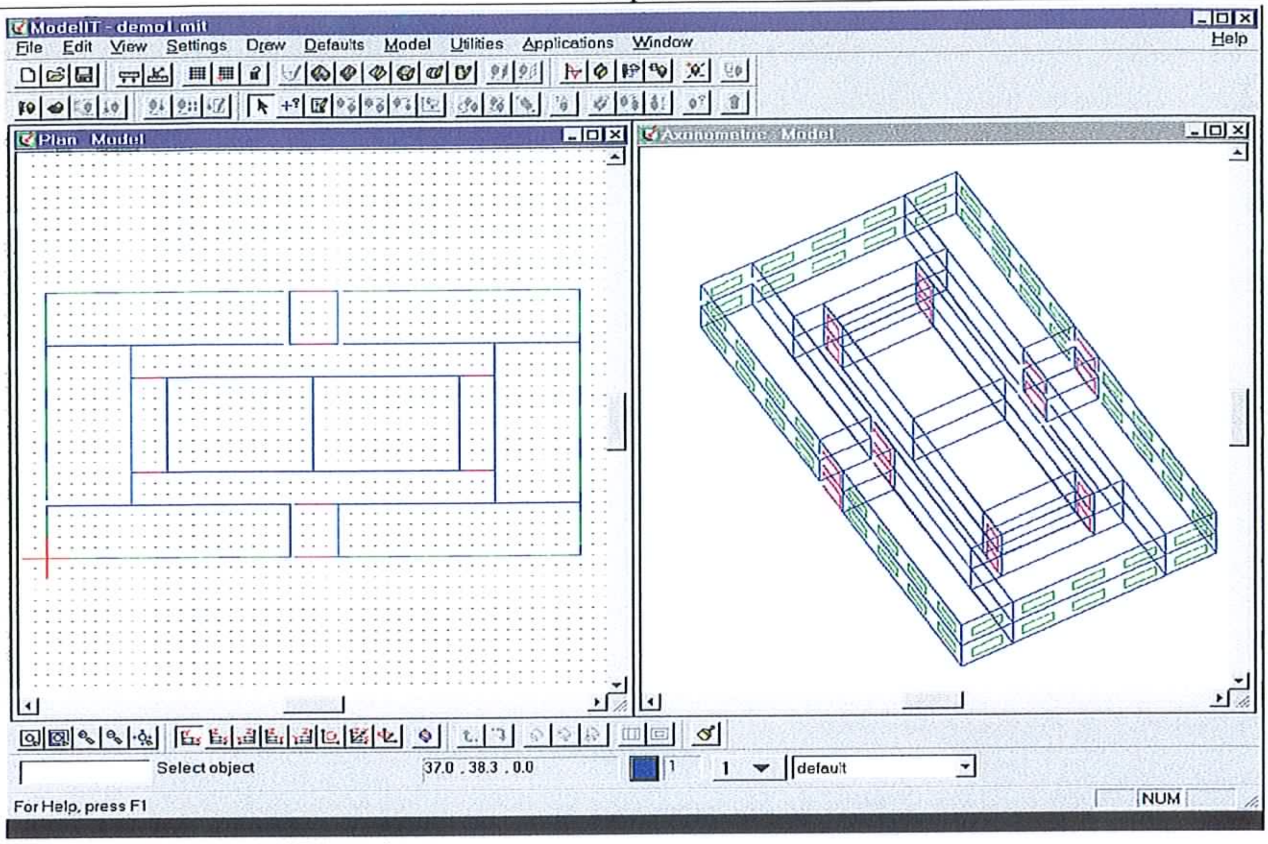


Figure 7.2: The ModellT interface.

ModellT is capable of operating independently of AutoCAD or drawings may be exported into ModellT from AutoCAD.

7.3 CostPlan

The second step in developing the required information for IDEAL is to use a program called CostPlan. Having created the model the capital cost of the building can be assessed in CostPlan. CostPlan enables the user to define a Cost Data File (.cst) that can be assigned to a model and the capital costs calculated.

In summary, CostPlan can use the 3D model created by ModellT, which contains exact measures for the dimensions of the building, e.g. total floor area, roof area, external wall area, etc. These parameters are then used to generate the elemental costs which are required for the Outline Cost Plan. The Costs data file defines the "rules" and price data that is used to calculate the individual costs. The "rule" defines which measure is to be applied to the unit price to give the cost.

CostPlan works by allowing the user to define a cost Category and each category has a number of elements.

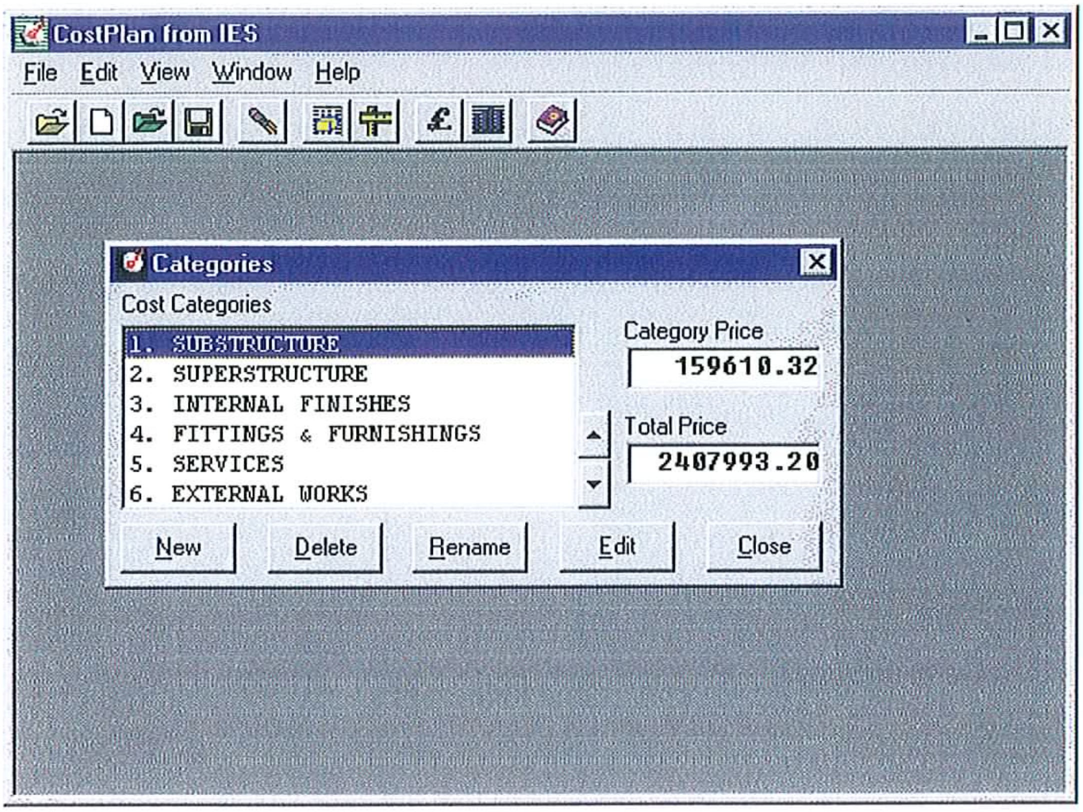


Figure 7.3: CostPlan Element Cost Categories.

The Cost Data File created to generate costs can then be used in IDEAL to help calculate capital costs.

7.4 APACHE-Calc

APACHE-calc generates the thermal performance characteristics of the model created. Heat Losses, heat gains and the net annual heating required are calculated using this program. These values are then exported into IDEAL.

7.5 IDEAL

IDEAL works by setting up a 'Base Case' analysis. This is the starting point of any IDEAL project. Other scenarios can be applied where the geometry, building operation, capital cost, etc. may change. The information for the Base Case is defined as follows:

- ModelIT is used to define the building model for analysis purposes and 'Exported to IDEAL'.
- CostPlan is used to define the cost file (.cst) for the model.
- The user runs IDEAL and defines if thermal, running cost, environmental or miscellaneous analyses are required.

Having reached this stage the following form is displayed:

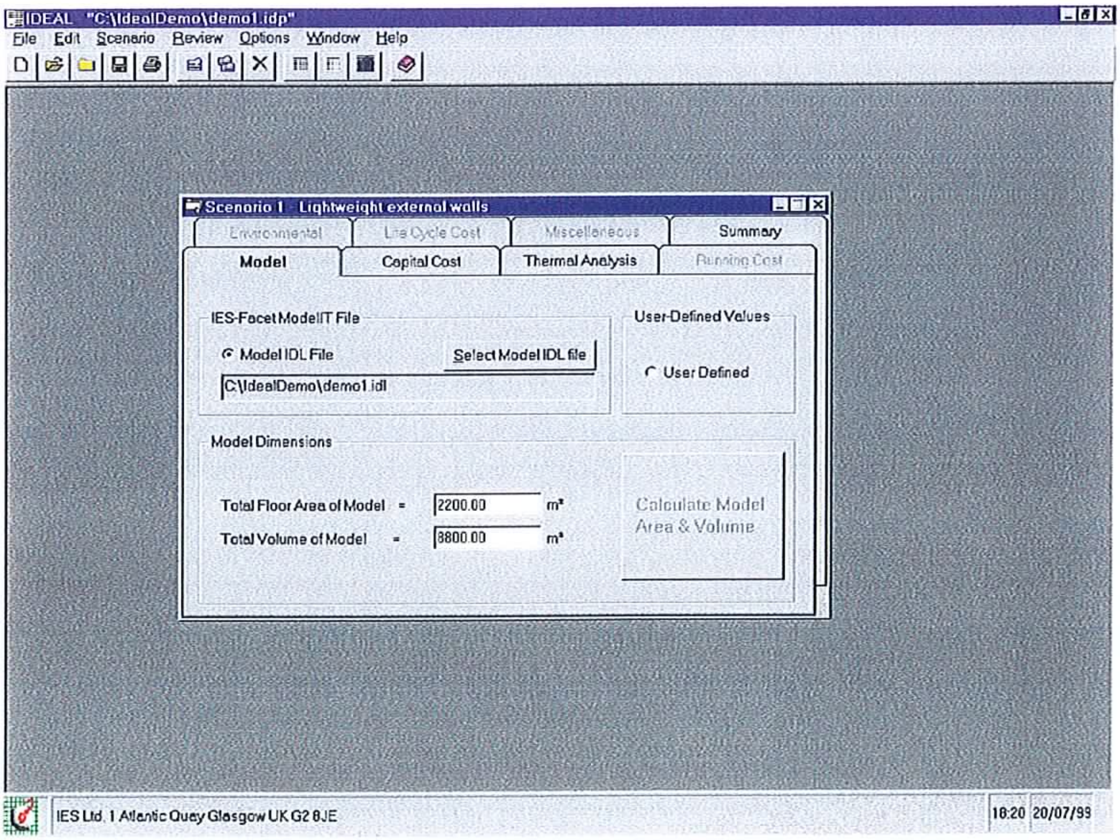


Figure 7.4: Base Case Analysis.

There are six data tabs:

1. Model,
2. Capital Cost,
3. Thermal Analysis,
4. Running Cost,
5. Environmental
6. and Miscellaneous.

7.5.1 Model

The Model tab allows the user to define the file created by ModelIT. Having entered this file the option to calculate the area and volume of the model can be invoked. Alternatively the user can define the area and volume of the building.

7.5.2 Capital Cost

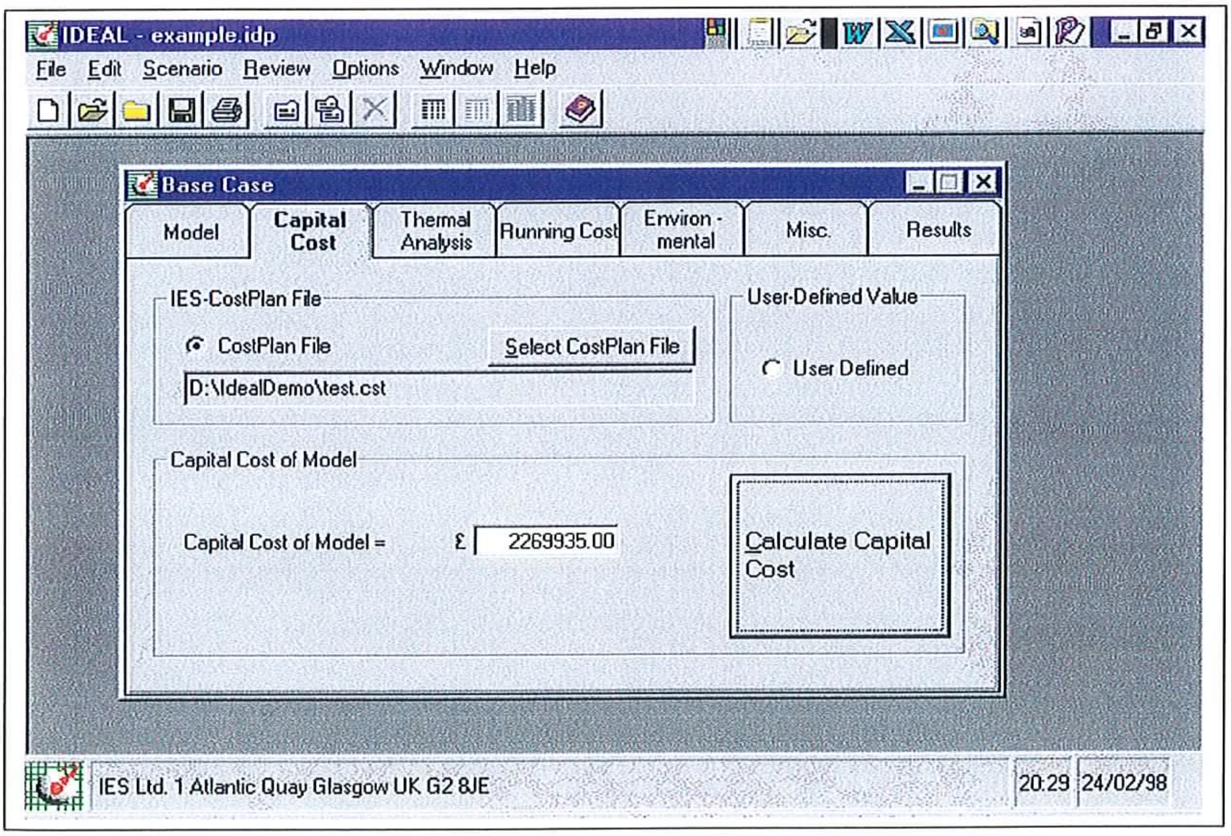


Figure 7.5: Capital Cost tab.

The cost data file can be defined through the Capital Cost tab. IDEAL calculates the capital costs associated for the building as CostPlan.

7.5.3 Thermal Analysis

When the thermal calculations are selected the user enters some supplementary information and APACHE-calc is invoked to calculate the appropriate heat loss and heat gain information. These values could have been entered via the user defined facility if APACHE-calc has been run.

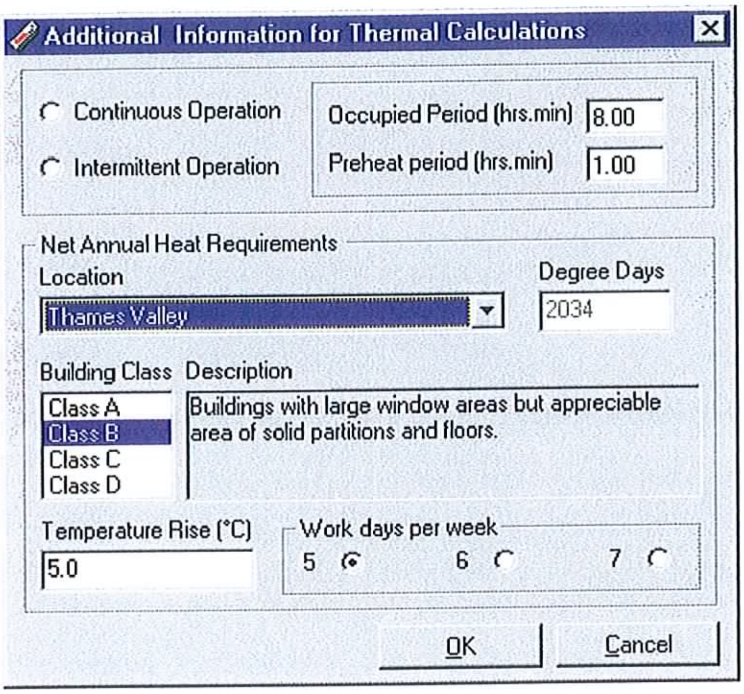


Figure 7.6: Thermal Calculations Additional Information tab.

Having completed the calculation process the thermal calculation tab will appear as follows:

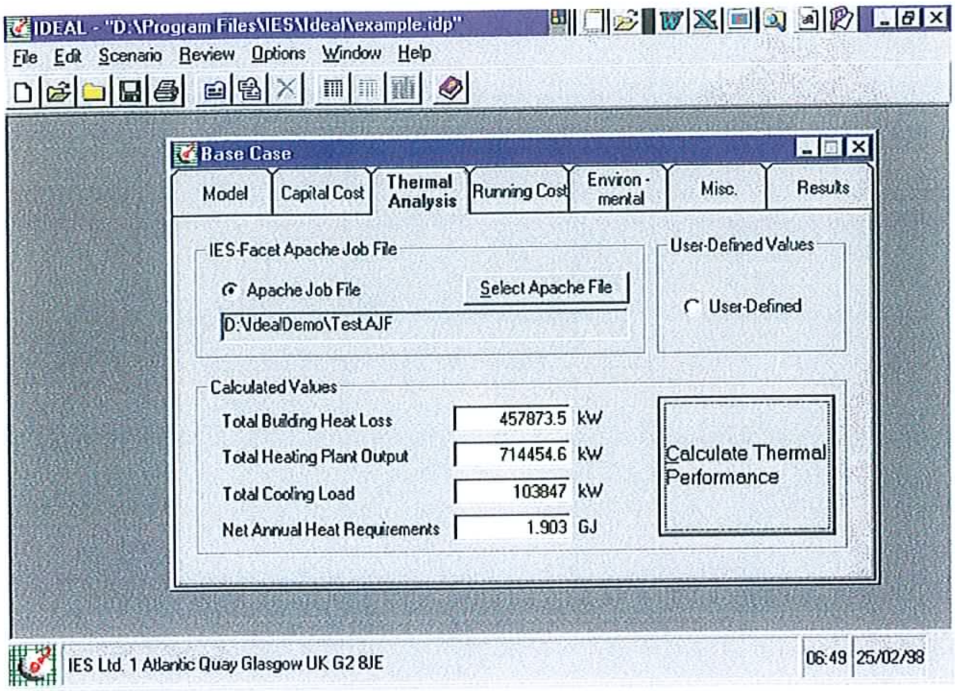


Figure 7.7: Thermal Calculation tab.

7.5.4 Running Cost

Currently the user must define the building running costs. IES are currently investigating the most effective method of calculating running costs. A complementary APACHE-sim or Ergon analysis may be carried out and the results entered into IDEAL by the user. The current Running Cost tab is indicated in Figure 7.8.

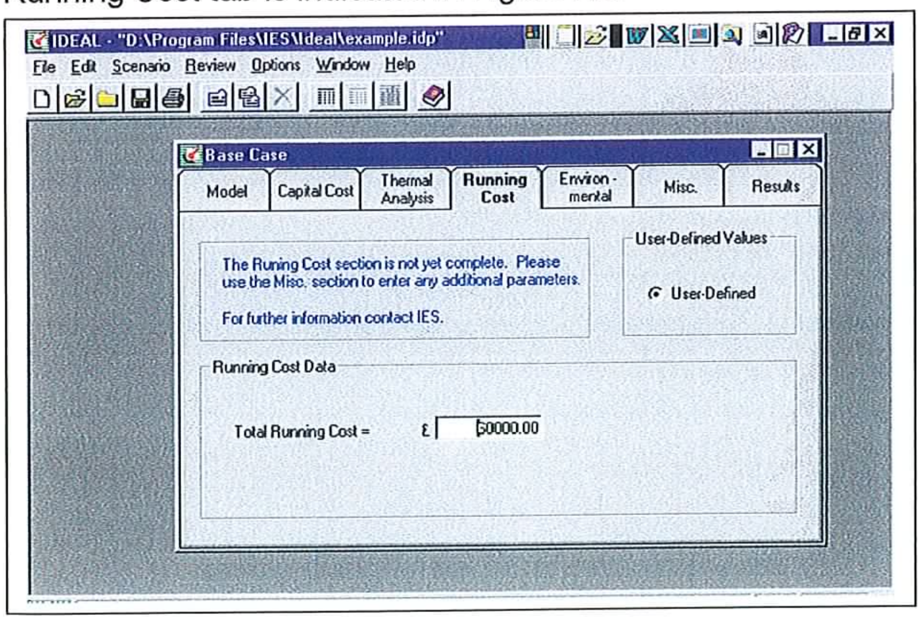


Figure 7.8: Running Cost tab.

7.5.5 Environmental

IES plan to calculate the following environmental parameters: Primary Energy Demand; Embodied CO2; Embodied Energy; CO2; CO; NOx; and SOx. A complementary APACHE-sim or Ergon analysis may be carried out and the results entered into IDEAL by the user.

The current Environmental tab is as follows:

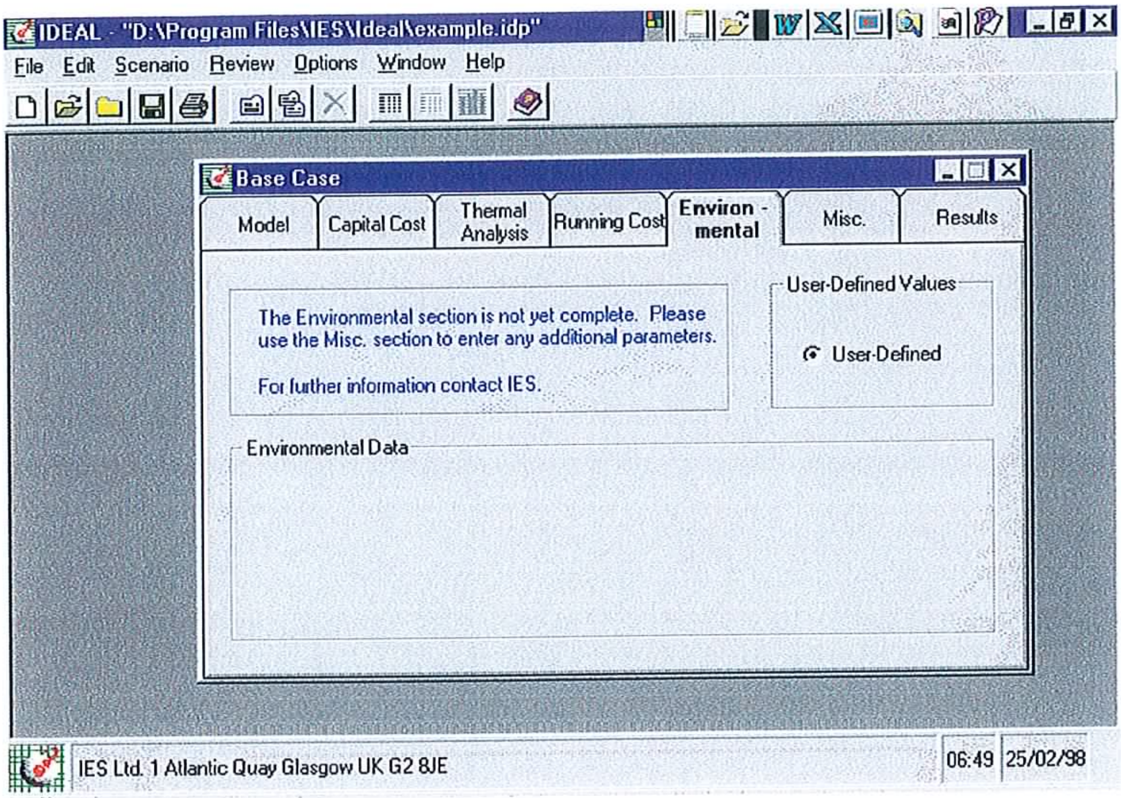


Figure 7.9: Environmental tab.

7.5.6 Miscellaneous

The Miscellaneous tab is extremely useful as it can be used for any variable important to the user, for example: the number of car park spaces; occupant comfort; the number of hours exceeding 24 Deg.C; percentage occupant satisfaction; etc.

The Miscellaneous tab at the start for the Base Case is shown in Figure 7.10.

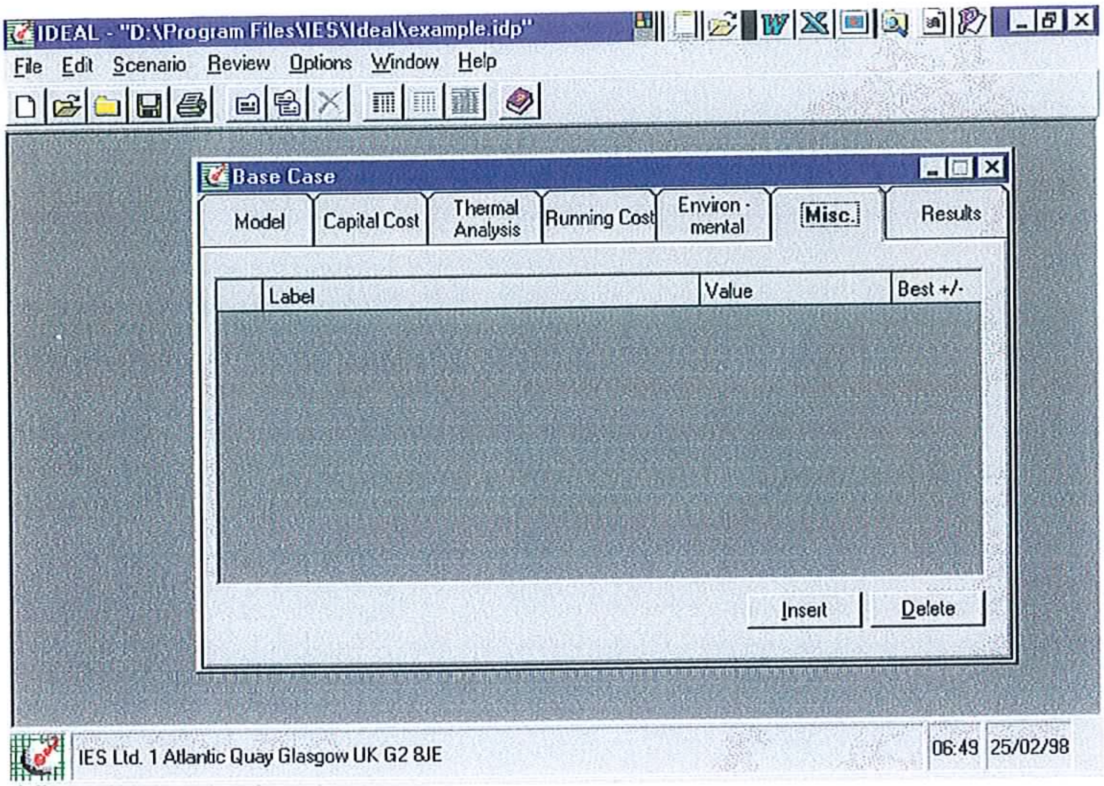


Figure 7.10: Miscellaneous tab.

7.6 Results

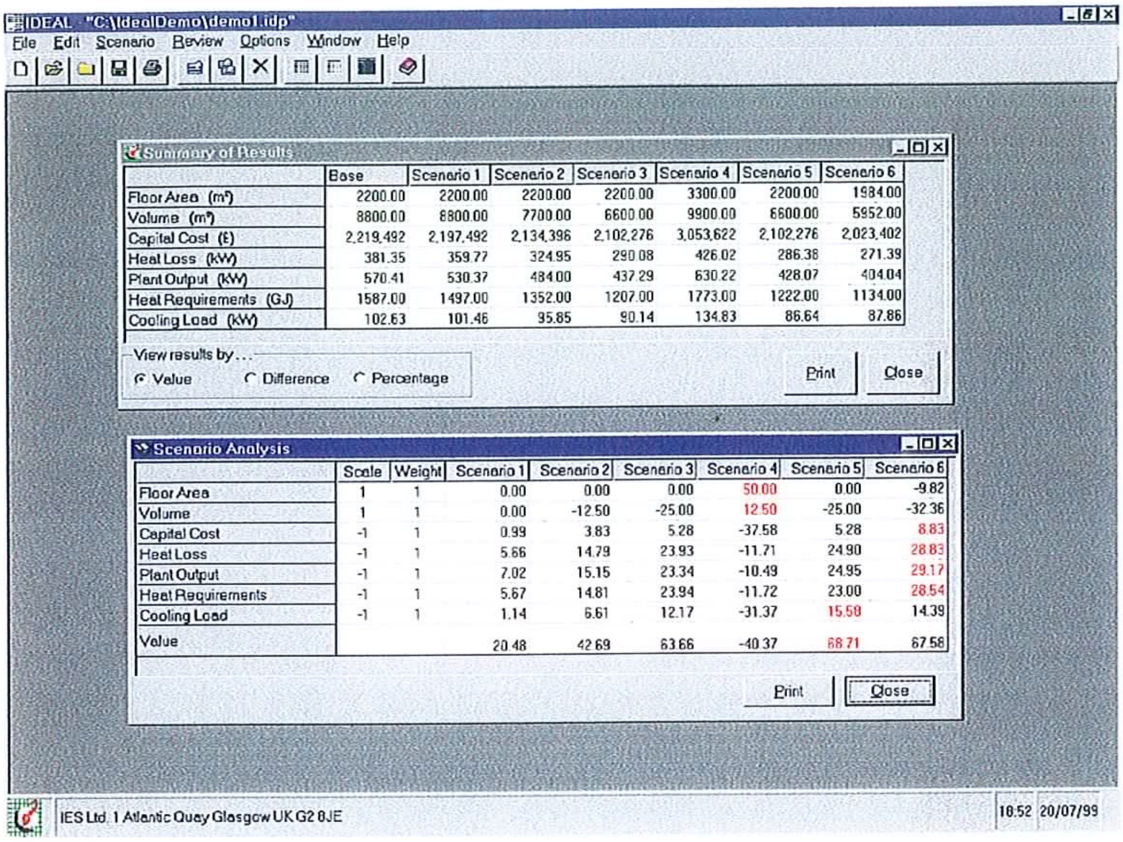
The purpose of the Results tab is to summarise the data entered and the calculated information. Figure 7.11 displays typical results.

7.7 New Scenario/Model

The thermal or construction characteristic of the building model developed in ModelIT may be altered in ModelIT and saved under a different name. ModelIT will generate a new IDM. The same process as described above is then completed for the new model. IDEAL allows for this new model or scenario to be compared with the initial 'Base Case' developed.

All the information pertaining to the Base Case is included in this new scenario. This may be carried out a number of times, hence producing a number of different scenarios.

The results for the Base case and all the scenarios are reviewed, as indicated in Figure 7.11 below.



	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Floor Area (m²)	2200.00	2200.00	2200.00	2200.00	3300.00	2200.00	1984.00
Volume (m³)	8800.00	8800.00	7700.00	6600.00	9900.00	6600.00	5952.00
Capital Cost (£)	2,219,492	2,197,492	2,134,396	2,102,276	3,053,622	2,102,276	2,023,402
Heat Loss (kW)	381.35	359.77	324.95	290.08	426.02	286.38	271.39
Plant Output (kW)	570.41	530.37	484.00	437.29	630.22	428.07	404.04
Heat Requirements (GJ)	1587.00	1497.00	1352.00	1207.00	1773.00	1222.00	1134.00
Cooling Load (kW)	102.63	101.46	95.85	90.14	134.83	86.64	87.86

	Scale	Weight	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Floor Area	1	1	0.00	0.00	0.00	50.00	0.00	-9.82
Volume	1	1	0.00	-12.50	-25.00	12.50	-25.00	-32.36
Capital Cost	-1	1	0.99	3.83	5.28	-37.58	5.28	8.83
Heat Loss	-1	1	5.66	14.79	23.93	-11.71	24.90	28.83
Plant Output	-1	1	7.02	15.15	23.34	-10.49	24.95	29.17
Heat Requirements	-1	1	5.67	14.81	23.94	-11.72	23.00	28.54
Cooling Load	-1	1	1.14	6.61	12.17	-31.37	15.58	14.39
Value			20.48	42.69	63.66	-40.37	68.71	67.58

Figure 7.11: Summary of Results and Scenario Analysis Tables

7.8 Scenario Analysis

This is the principal tool for comparing the relative merits of the various scenarios against the Base Case. See Figure 7.11 above.

IDEAL uses the percentage differences between the Base Case and each scenario as the basis for calculating the relative performance of each scenario against the Base Case. The calculation procedure is as follows:

- The Percentage difference between the Base Case and scenario is calculated for each variable.
- The percentage difference is multiplied by the Scale and Weighting Factor values.

- The values for each variable are summed and the scenario with the highest value is deemed the best scenario, and better than the Base Case if it is a positive value.

7.9 Conclusion

This chapter describes the operation of IDEAL and the other programs which run in sequence with this beta version of IDEAL. A lot of the recommendations made in Chapter 6 have been implemented in the program and described in this chapter. However, due to time restraints set down by this thesis, it was not possible to include for Running and Environmental Costs in this program. IES intend to fully implement all recommendations into IDEAL and it is hoped to launch the full program onto the market this year.

It is often said "that the proof of the pudding is sometimes in the eating", and I will therefore adopt the essence of this by carrying out a detailed case study of IDEAL. The work is included in Chapter 8.

Chapter 8: Early Design Stage Case Study

8.1 Introduction

The purpose of this case study is to investigate the Early Design Stage computer programme developed in co-ordination with the industrial partner and in-line with the findings of Questionnaire/Survey and as suggested in the programme specification. It is the intention to highlight the advantages this new programme brings to the design team, especially in terms of the information available to the engineer, architect and the client at the early design stage.

It is now more widely acceptable that the early design stage decisions have the most significant impact on a building's energy and environmental performance. Thus architects and engineers require a range of information on their design proposals so that the best decisions can be made. This integrated early design stage computer programme provides this information.

In this case study, a "Base Building" is firstly created using an integrated data model and establishing the buildings thermal and environmental characteristics. Changes are then made to the Base Building thus creating different scenarios. In order to get a broad appreciation of the range and benefits of the programme, there will be six scenarios.

8.2 Base Building

This Base building for the purpose of this case study is a two-storey office building with a total area of 2,200m^2. The building comprises of open plan offices in the central core and is surrounded by perimeter offices on both floors. The Base building is simple in design; hence highlighting that, buildings need not be complex in nature to warrant this kind of study. There are several assumptions that have been made with this building model in order to make this building as realistic as possible and also to enable a full analysis to be carried out. See below for a wire frame view of this model.

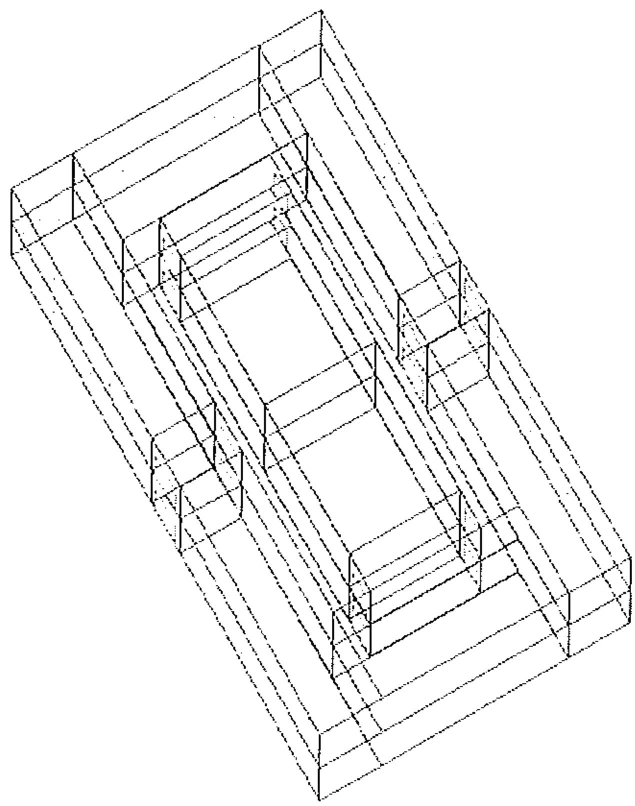


Figure 8.1 Base Building

8.3 Assumptions

Location:	Dublin
Weather Profile:	Dublin

This weather profile for Dublin assumes an external winter design temperature of $-3^{O}C$. Variables for each month such as dry bulb and wet bulb temperatures are included in the heat loss and heat gains calculations. See Appendix D for these weather variables.

8.4 Construction Details

The construction details for the Base Building is as follows:

Element	**Construction Type**	**U-Value (W/m^2K)**
Internal Walls	13mm Plaster (Lightweight), 105mm Brickwork (Inner Leaf) & 13mm Plaster (Lightweight)	1.767
External Walls	Lightweight Concrete Block, Polyinsulation & Plasterboard	0.436
Glazing	6mm Pilkington Single Glazing	5.65
Roof	19mm Asphalt, 75mm Screed, 150mm Cast Concrete (Dense) & 13mm Plaster (Dense)	1.956
Ground Floor	Standard Floor Construction (Insulated to 1995 Regulations)	0.421
Door	Wooden Door	2.065
Roof Glazing	Polycarbonate Double Glazed Roof Lights	3.89
Internal Glazing	6mm Clear Float Glazing	5.00
Ceiling	100mm Reinforced-Concrete Ceiling	3.272

Table 8.1: Thermal Construction Details

Refer to Appendix C for Thermal Calculation of all construction elements.

The buildings thermal characteristics will be determined based on the above construction types. This will provide a "Base Case" thermal profile of the building in which the heat gains and heat losses may be established. Following the analyses of the thermal characteristics of this building model, a number of the construction types will then be altered, and the heat gains and losses are re-calculated. This will highlight the effects of for example increasing the external wall insulation thickness and hence its impact on the buildings energy requirements. Construction modifications like this can provide the design team with invaluable information quickly and help to access at an early stage of the project concept the advantages or disadvantages of such modifications from an energy, cost and environmental point of view.

8.5 Orientation

The orientation and geometry of a building can have a significant impact of the building's energy usage. For example, a large percentage of glazing on the south façade of the building would result in high summer heat gains. By altering the orientation, which can be done very easily with a computer model, can determine the optimum position of the building.

ORIENTATION 0^0

8.6 Daily Profile

The purpose of creating a daily profile is to establish the daily working profile of the building so as to determine when the building's peak loads occur. For this building, in which the author has assumed to be an office, a normal office profile has been created. The graph below indicates this profile. As the building is an office, the author has assumed that the building will be unoccupied during the weekend; hence this will have an impact of the annual fuel and energy costs.

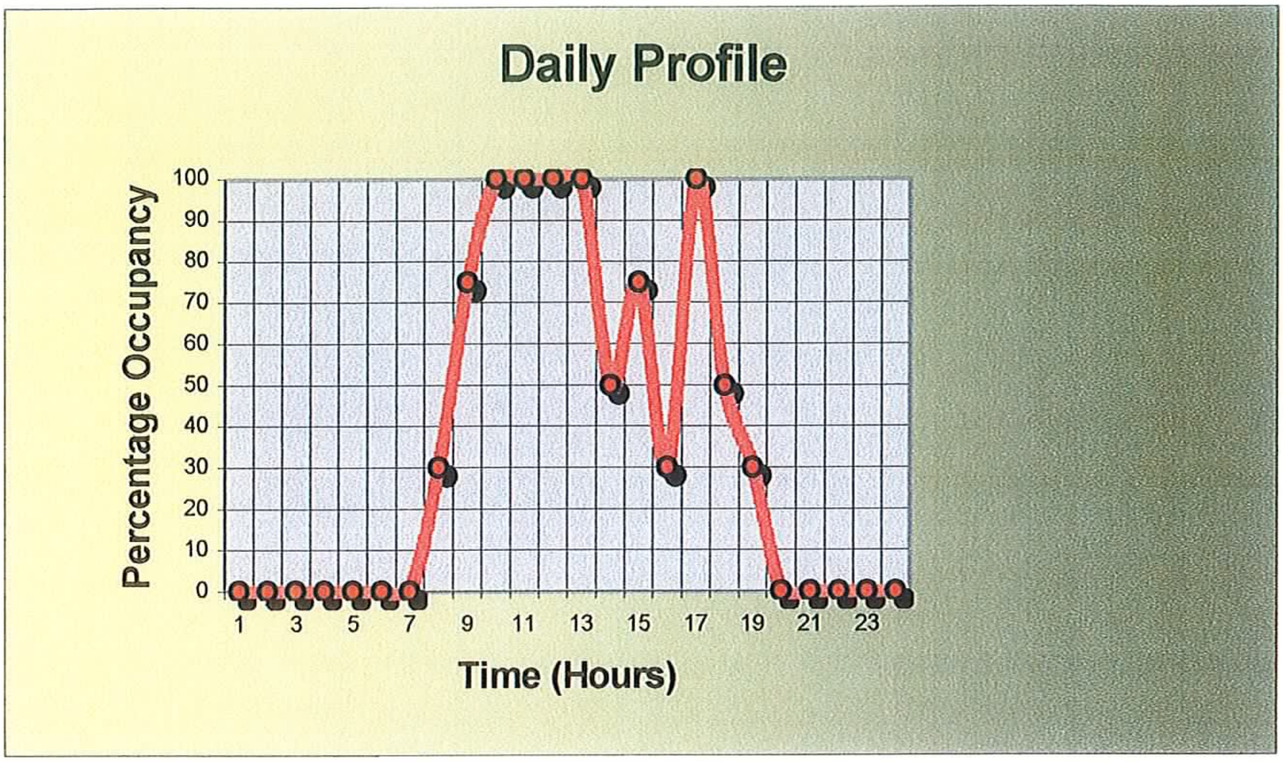


Table 8.2: Daily Occupancy Profile

8.7 Internal Design Conditions

<u>GENERAL</u>

Comfort:

- Lower Temp. Limit	15 ^{o}C
- Upper Temp. Limit	30 ^{o}C
Lettable Area	80 %
Circulation Area	20 %

THERMAL

Winter Indoor Temp.	19 ^{O}C
Emitter Radiant Fraction	0.3
Summer Min. Indoor Temp.	19 ^{O}C
Summer Max. Indoor Temp.	23 ^{O}C
Summer Min. Percentage Saturation.	30 %
Summer Min. Percentage Saturation.	70 %
Cooling Device Radiant Fraction.	0
Solar Reflected Fraction.	0.05
Furniture Mass Fraction.	1

LIGHTING

Illuminance Level.	500 lux
Limiting Glare Index.	19
Working Surface Height.	0.75 m
Mounting Height.	2.7 m
Luminance Maintenance Factor.	0.9
Lamp Replacement Period.	5000 hours
Room surface Maintenance Factor	0.9
Lamp Survival Factor	1
Luminaire.	Crompton Dulcet with Opal Diffuser
Lamp.	1200mm Polylux T8 Lamp
Colour.	WW

CASUAL GAINS

People

- Floor Area per Person	10 m^2
- Max. Sensible Gain	90 W/person
- Max. Latent Gain	60 W/person
Fluorescent Lighting	10 W/ m^2
Computers	30 W/ m^2

AIR EXCHANGE

Infiltration	0.5
Natural Ventilation	0.5 ach/hr
Mechanical Ventilation	None

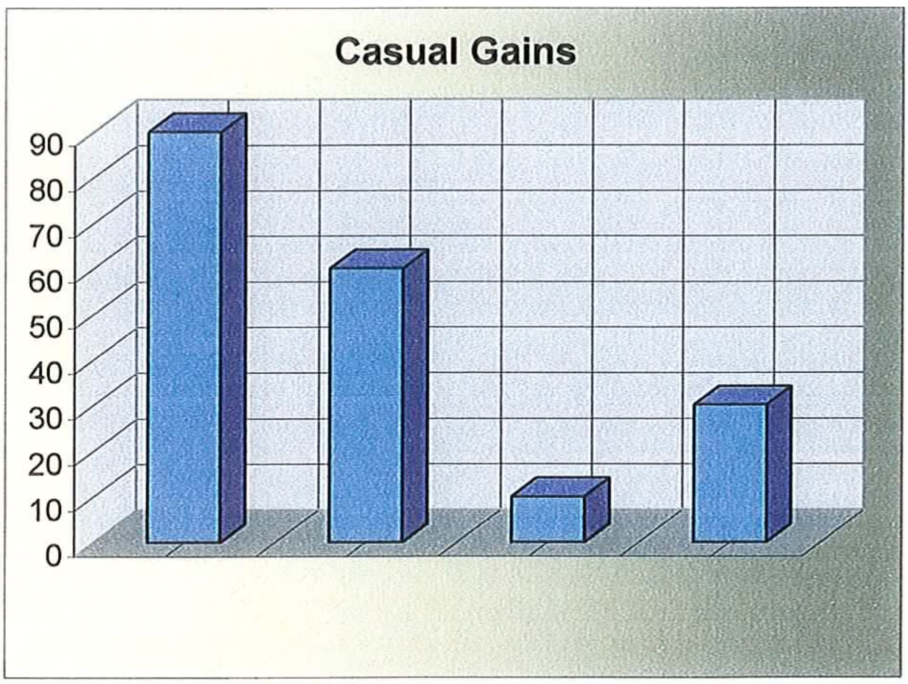


Table 8.3: Casual Gains

With so many variables within the design of a building, it would be impossible to make several changes in one particular scenario and hope to evaluate these changes successfully. Therefore, only making construction modifications, such as altering the thermal performance of the building's construction. The changes made throughout the different scenarios would be typical questions posed by the architect, client and indeed the building services' engineer. Questions such as "what is the impact on the Capital Costs and thermal performance by adding extra insulation?" This program can answer such questions. The table below indicates the different changes that are made throughout the scenarios.

Table 8.4: Summary Table of Scenario Changes.

Scenario Number	**Change from Base Building**	**Purpose of Change**
1.	External Walls Modified to a Lightweight Construction.	Effects on Heat Loss and Gains by altering the External Walls Thermal Transmittance can be Evaluated.
2.	Reduction in Floor to Ceiling Height from 4.0 meters to 3.5 meters.	This Change impacts not only the Thermal Characteristics, but also the overall Capital Costs.
3.	Reduction in Floor to Ceiling Height from 4.0 meters to 3.0 meters.	As with Scenario Number 2, a reduction in Building Volume has a significant impacts on the Performance of the Building.
4.	Additional Floor, increasing the volume to 9,900m^3.	This change aids in Evaluating the effects on a Volume increase on the Building Performance.

5.	Set Point Temperature Modification.	The overall Annual energy requirements can be assessed by this change.
6.	Atrium added to Building.	Atriums are Popular with Environmentally Aware Client. The effect on the Costs and Thermal Performance can therefore be evaluated easily with this addition to the Base Building.

The thermal characteristics of the Base Building are as follows:

Total Floor Area	2,200 m^2
Total Volume	8,800 m^3
Capital Costs	£2,219.492
Total Building Heat Loss	381.35 kW
Total Heating Plant Output	570 kW
Net Annual Heating	1587 GJ
Total Cooling Load	103 kW

Table 8.5: Base Building Result Output.

8.8 Scenerio No. 1

In this scenario, the external walls are modified to a lightweight construction. Therefore, the thermal characteristic and thermal transmittance of the building are altered from that of the base building. This would be a common question proposed by the design team. All following six scenarios will have the same thermal properties as this scenario, i.e. a lightweight external wall. The reason is to change only one particular element or property, so as to avoid confusion in interpreting the results. It is possible; however, to make as many changes as the design team would like from the Base Building.

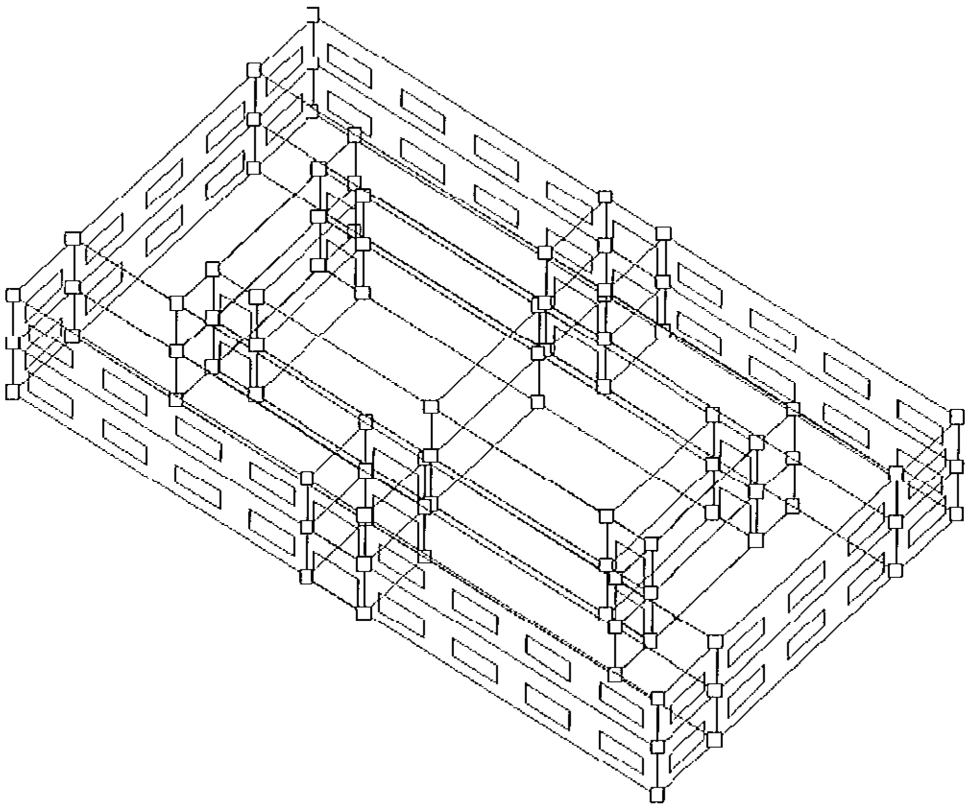


Figure 8.2 Scenario No. 1 Model

Total Floor Area	2,200 m^2
Total Volume	8,800 m^3
Capital Costs	£2,197.492
Total Building Heat Loss	360 kW
Total Heating Plant Output	530 kW
Net Annual Heating	1497 GJ
Total Cooling Load	101 kW

Table 8.6: Scenario No.1 Result Output.

8.9 Scenario No. 2

The floor to ceiling height is reduced from 4 meters to 3.5 meters in this scenario. The Thermal properties are not changed, so as to establish the impact of reducing the building height.

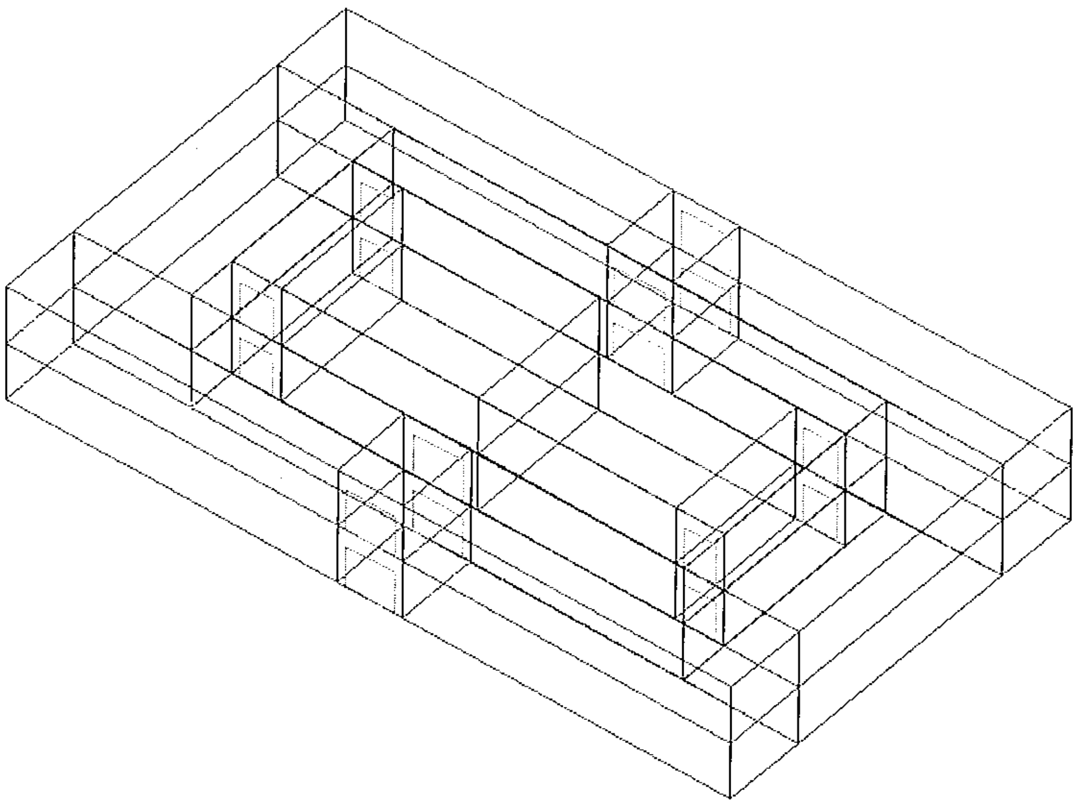


Figure 8.3: Scenario No. 2 Model

Total Floor Area	2,200 m^2
Total Volume (3.5m high floor)	7,700 m^3
Capital Costs	£2,134.396
Total Building Heat Loss	325 kW

Total Heating Plant Output	485 kW
Net Annual Heating	1352 GJ
Total Cooling Load	96 kW

Table 8.7: Scenario No.2 Result Output.

8.10 Scenario No. 3

The floor to ceiling height is reduced further in this scenario. A client or architect may wish for example to analyse the effects in cost and thermal performance of reducing the floor to ceiling height to the minimum standards. Again, it provides an additional tool in the decision making process of a building construction project.

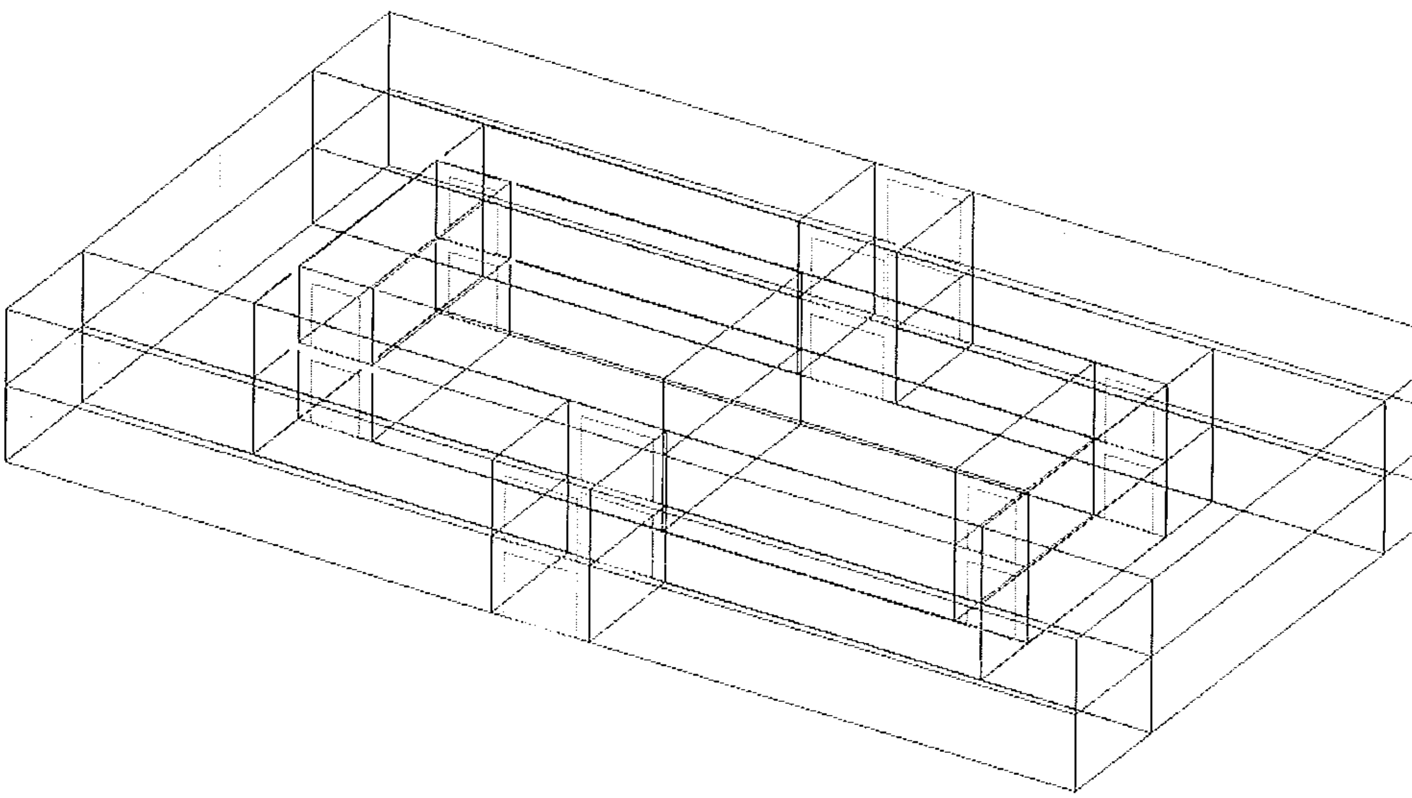


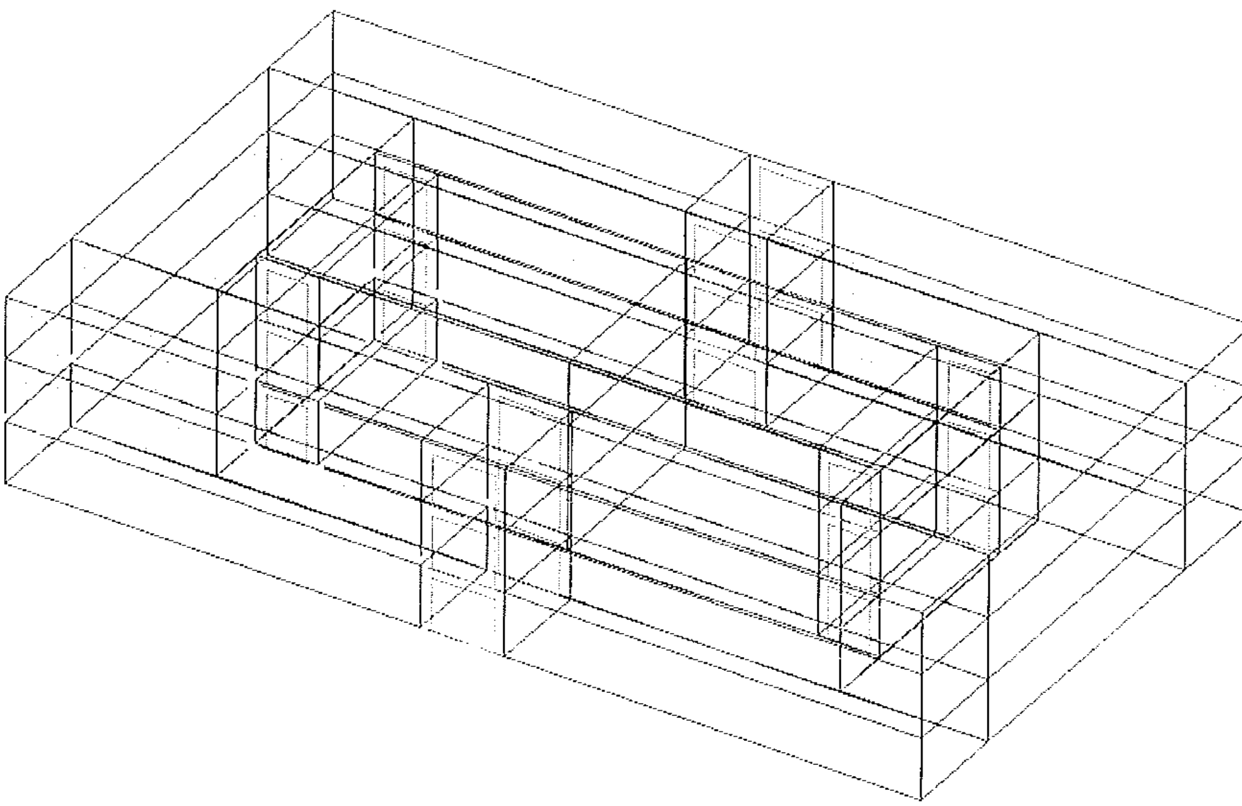
Figure 8.4: Scenario No. 3 Model

Total Floor Area	2,200 m^2
Total Volume (3.0m high floor)	6,600 m^3
Capital Costs	£2,102.276
Total Building Heat Loss	290 kW
Total Heating Plant Output	437 kW
Net Annual Heating	1207 GJ
Total Cooling Load	90 kW

Table 8.8: Scenario No.3 Result Output.

8.11 Scenario No. 4

Figure 8.5: Scenario No. 4 Model



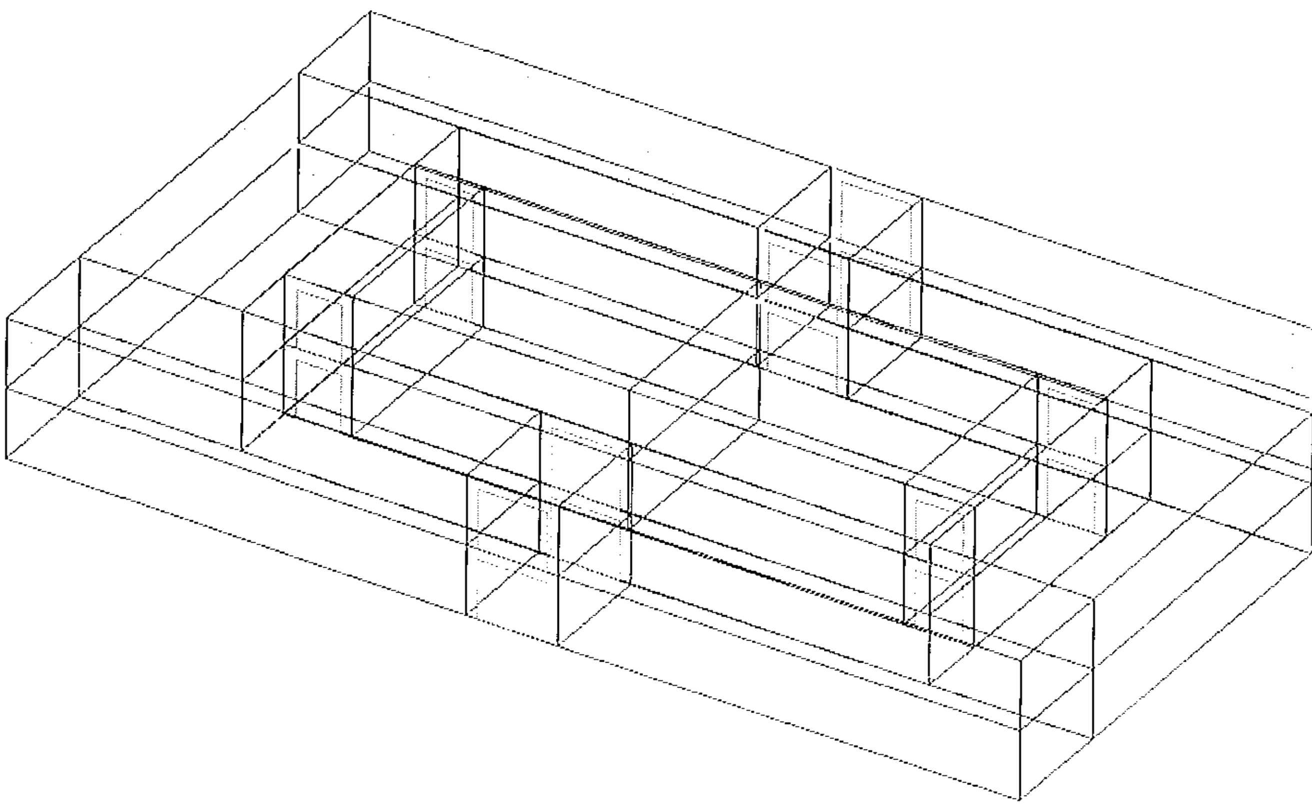
Total Floor Area	3,300 m^2
Total Volume (3.0m high floor)	9,900 m^3
Capital Costs	£3,053.622
Total Building Heat Loss	426 kW
Total Heating Plant Output	630 kW
Net Annual Heating	1773 GJ
Total Cooling Load	135 kW

Table 8.9: Scenario No.4 Result Output.

8.12 Scenario No. 5

This scenario unlike Scenario No. 4 has two floors, as per the Base Building. However, the temperature set points have changed. This scenario can be evaluated against Scenario No. 3, as the only difference is the modified temperature set points.

Figure 8.6: Scenario No. 5 Model



Total Floor Area	2,200 m^2
Total Volume	8,800 m^3
Capital Costs	£2,102.276
Total Building Heat Loss	286 kW
Total Heating Plant Output	428 kW
Net Annual Heating	1222 GJ
Total Cooling Load	87 kW

Table 8.10: Scenario No.5 Result Output.

8.13 Scenario No. 6

This scenario includes the addition of an atrium to the building. The atrium has been taken from the total Base Building floor area.

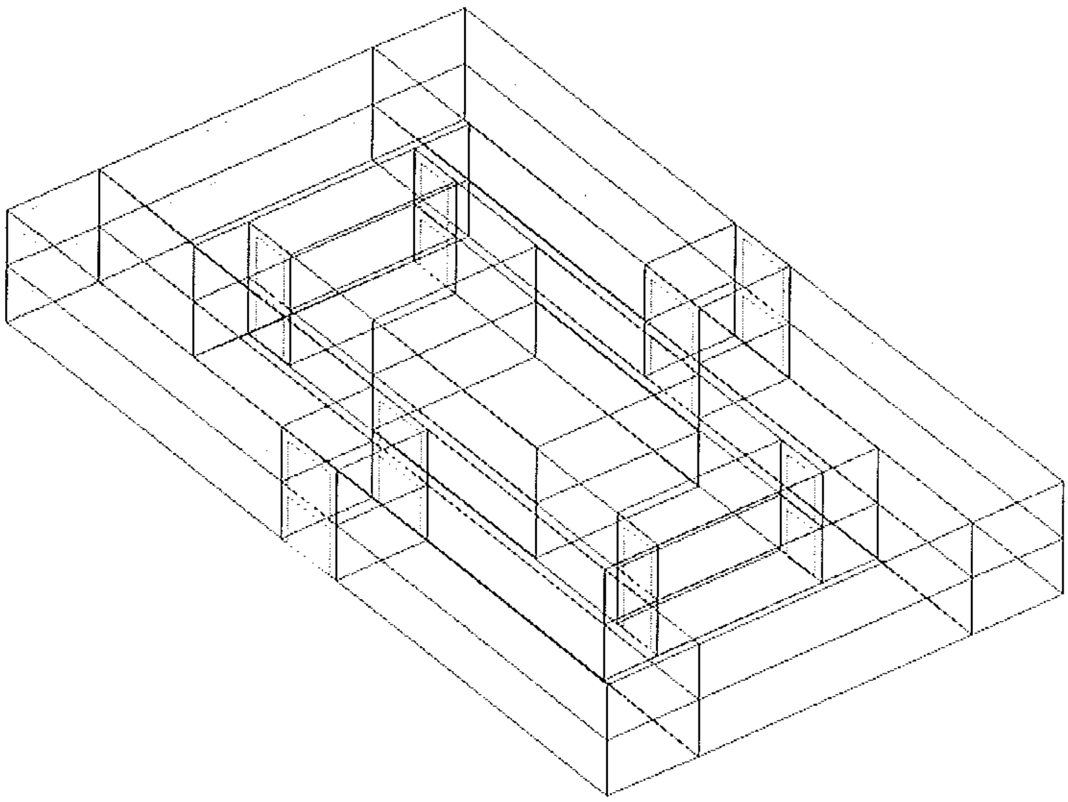


Figure 8.7: Scenario No. 6 Model

Total Floor Area	1,984 m^2
Total Volume	5,952 m^3
Capital Costs	£2,023.402
Total Building Heat Loss	271 kW
Total Heating Plant Output	405 kW
Net Annual Heating	1135 GJ
Total Cooling Load	88 kW

Table 8.11: Scenario No.6 Result Output.

The above scenarios illustrate the range of different results possible in this early design stage program and the benefits from an analyzing point of view. The development these particular scenarios would be typical of questions posed by the design team at an early stage in a project. The Base Building being the design teams first attempt at developing the client's brief. The scenarios evolve based on queries, as can be seen throughout the scenarios. For example, the architect may initially want to know the impact on the design by altering thermal performance of the structure, which leads into scenario No.1, the reducing of the height from 4.0 meters to 3.5 meters.

8.14 Analysis of The Results

This table indicates the Percentage difference that each scenario varies from the Base Building.

	Floor Area m^2	Volume m^3	Capital Cost £	Heat Loss kW	Plant Output kW	Heat Requirements GJ	Cooling Load KW
Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scenario 1	0.00	0.00	-0.99	-5.66	-7.02	-5.67	-1.14
Scenario 2	0.00	-12.50	-3.83	-14.79	-15.15	-14.81	-6.61
Scenario 3	0.00	-25.00	-5.28	-23.93	-23.34	-23.94	-12.17
Scenario 4	50.00	12.50	37.58	11.71	10.49	11.72	31.37
Scenario 5	0.00	-25.00	-5.28	-24.90	-24.95	-23.00	-15.58

Scenario 6	-9.82	-32.36	-8.83	-28.83	-29.17	-28.54	-14.39

Table 8.12: Percentage Summary of Results

This table indicates the Value difference that each scenario varies from the Base Building.

	Floor Area m^2	Volume m^3	Capital Cost £	Heat Loss kW	Plant Output kW	Heat Requirements GJ	Cooling Load KW
Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scenario 1	0.00	0.00	-22000	-21.58	-40.04	-90.00	-1.17
Scenario 2	0.00	-1100.0	-85096	-56.40	-86.41	-235.00	-6.78
Scenario 3	0.00	-2200	-117216	-91.27	-133.1	-380.00	-12.49
Scenario 4	1100	1100	834130	44.67	59.81	186.00	32.20
Scenario 5	0.00	-2200	-117216	-94.97	-142.3	-365.00	-15.99
Scenario 6	-216.	-2848	-196090	-109.9	-166.3	-453.00	-14.77

Table 8.13:Value Summary of Results

8.15 Scenario Analysis

	Floor Area m^2	Volume m^3	Capital Cost £	Heat Loss kW	Plant Output kW	Heat Requirements GJ	Cooling Load KW	Value
Scale	1	1	-1	-1	-1	-1	-1	
Weighting Factor	6	2	10	1	3	1	3	
Scenario 1	0.00	0.00	9.91	5.66	21.06	5.67	3.42	**45.72**
Scenario 2	0.00	-25.00	38.34	14.79	45.45	14.81	19.82	**108.21**
Scenario 3	0.00	-50.00	52.81	23.93	70.01	23.94	36.51	**157.20**
Scenario 4	**300.0**	**25.00**	-375.82	-11.71	-31.46	-11.72	-94.12	**-199.83**
Scenario 5	0.00	-50.00	52.81	24.90	74.86	23.00	46.74	**172.31**
Scenario 6	-58.9	-64.73	**88.35**	**28.83**	**87.50**	**28.54**	43.17	**152.75**

Table 8.14: Scenario Analysis
Note: Highlighted values denote Best Figures.

The scale value is used for calculating the best scenario. Factors are assigned to each variable being examined. The best options have positive values and negative values to the least important options. Therefore for example the "-1" assigned to the Capital Costs above means that it is not BETTER to have higher Capital Costs.

The Weighting Factors are used for comparing different scenarios, hence if Capital Cost is the most important to the client for example, a high weighting factors will be assigned to Capital Costs. This is the case with the above Scanario's as a Weighting Factor of "10" is assigned to the Capital Costs. The Weighting Factors can have a dramatic effect on the comparison between scenarios. It is important that these values represent the clients brief and the design team's aspirations.

Therefore based upon the above Scale and Weighting Factors, Scenario No. 5 produced the most favorable results. The Weighting Factors works as follows using Scenario No. 5 as an example:

	Floor Area m^2	Volume m^3	Capital Cost £	Heat Loss kW	Plant Output kW	Heat Requirements GJ	Cooling Load KW	Value
Scale	1	1	-1	-1	-1	-1	-1	
Weighting Factor	6	2	10	1	3	1	3	
Scenario 5 Percentage Summary	0.00	-25.00	-5.28	-24.90	-24.95	-23.00	-15.58	
Multiply W.F by % Summary	6 x 0 = 0.00	2 x (-25) = -50.00	10 x (-5.28) = -52.81 (Scale = -1) => 52.81	1 x (-24.90) = -24.90 (Scale –1) => 24.90	3 x (-24.95) = -74.86 (Scale –1) => 74.86	1 x (-23.00) = -23.00 (Scale = -1) => 23.00	3 x (-15.58) = -46.74 (Scale = -1) => 46.74	
Scenario 5	0.00	-50.00	52.81	24.90	74.86	23.00	46.74	**These all add to give a total of 172.31**

Table 8.15: Scenario No.5 Weighing and Scaling Factors Calculation

Again the benefits of the program are illustrated in the above Tables. The design team can quickly make important decision based upon the brief and budget limitations on which option is most beneficial and cost effective.

From an energy load point of view, Scenario 6 is the best option, using less heating and cooling. Therefore an energy conscience client or design team can easily identify Scenario No. 6 as the least user of energy. If the design team valued the energy performance as the most important factor in the early design stage decision making, the Scale and Weighting factors would be altered in preference of the Energy consumption, as illustrated in the Analysis Scenario below.

	Floor Area m^2	Volume m^3	Capital Cost £	Heat Loss kW	Plant Output kW	Heat Requirements GJ	Cooling Load KW	Value
Scale	1	1	-1	-1	-1	-1	-1	
Weight	6	2	10	5	10	1	10	
Scenario 1	0.00	0.00	9.91	28.29	70.20	5.67	11.4	**125.47**
Scenario 2	0.00	-25.00	38.34	73.95	151.49	14.81	66.06	**319.65**
Scenario 3	0.00	-50.00	52.81	119.67	233.38	23.94	121.70	**501.50**
Scenario 4	**300.0**	**25.00**	-375.82	-58.57	-104.8	-11.72	-313.75	**-539.71**
Scenario 5	0.00	-50.00	52.81	124.52	249.54	23.00	**155.80**	**555.67**
Scenario 6	-58.9	-64.73	**88.35**	**28.83**	**291.67**	**28.54**	143.92	**573.01**

Table 8.16: Summary of Scenario Results

Each different factor can be analyzed against each other to arrive at the most appropriate building. The program really acts as a guide, leading the design team towards their most preferred design option.

This design tool has also the following advantages:

- Improves Communication within the design team.
- Helps to deliver the clients brief more Efficiently and Effectively.
- The computer model built can be used for more detailed study of the design process.
- Better design decisions on energy, risk of over-heating etc. which is best carried out at the early design stage.
- Less need to change the design as the design progresses as major decisions on the building's form, layout, orientation etc. have been based on better information.

8.16 Suggestions

Throughout my thesis, the author has continuously made references to the advantages that computer simulation has over the steady state method of calculating heating and cooling loads. The heat gain and loss results as illustrated in the above Tables are all based upon Steady State calculation methods. While these results indicate how design changes improve or reduce the loads on a building, they are not as accurate as simulation results may be. We cannot for example analysis the total energy usage per year; the CO2 produced by different scenarios, the effects of the lighting loads by natural day lighting etc. This is not to say that this information is not available. One main advantage with this Early design stage computer programme is that once the integrated model is built, it can be used by other programmes within the IES suite of programmes. There is no reason therefore why a simulation could not be run on all the scenario's described previously using Apachesim. Apachesim is much more sensitive to changes than any steady state method. For example, changing insulation type or thickness will yield more information about the heat loss, gains and plant output than is possible using steady state methods.

However, Apachesim uses actual "weather files" when calculating the heating and cooling loads. This obviously requires a significant amount of computer power in the calculation process than maximum and minimum values. Hence the speed of obtaining results takes a lot longer. One advantage of IDEAL is that the results can be obtained quickly. This would not be the case therefore if different scenario's were used in Apachesim compared to steady state calculations. Nevertheless, with ever increasing computer power, there is no reason why IDEAL will not in the future have the option of running both simulation and steady state calculations.

Chapter 9: Conclusions

9.1 Conclusions

The aim of this thesis was to investigate the need for an co-ordinated early design stage computer program which was easy to use and fully integrated with other design programs to assist the design stage in addressing design approaches which aid in the reduction of energy usage.

Chapter One of this thesis investigated the members of the design team, current design approaches and building design procedures. This set out and identified the parties who have influence over design decisions.

Chapter Two directly compared two design approaches used by building services engineers, namely the steady state method and the simulation method. The advantages of the simulation method were determined. An intensive critical literature review was carried out on the simulation programs available both commercially and for education purposes to ensure a similar program did not exist. The research identified a missing program: an easy to us integrated early design stage program, which provides information quickly to the design team, helping to reduce and address the impact that buildings have on the environment.

A questionnaire/survey of building services engineers was carried out and the results were included in Chapter Three. While identifying the simulation software was not widely used by the engineers, the survey encouragingly recognised the benefits an early design stage program would bring to the design process.

Chapter Four gave the opportunity to provide a detailed investigation into the industrial partner for this thesis, Integrated Environmental Solutions (IES) which included their history, projections for the future and an examination into the suite of simulation programs. From this study, it was recognised that firstly an early design stage program was not offered by IES, but also that an early design stage tool could be easily accommodated into their suite of software.

Having, identified the market requirements for an early design stage program, an intensive analysis of the projects in which simulation software was used as an integral part of the design process was carried out in Chapter Five. The benefits of simulation technology and the advantages from an energy perspective were established in this chapter, but importantly, lessons were learned from which an early design stage program could have addressed sooner and to the overall benefit of the project.

Chapter Six describes the specification requirements for an early design stage program and Chapter Seven provides a detailed procedure of the newly written BETA version of the program.

In chapter Eight, the BETA version of the early design stage program is tested and the results of the test analysed. The testing consisted on building a "Base Case" model with assumed constructions and profiles. Six scenarios, each with one geometrical or construction change from the previous scenario, were then performed. All six scenarios were analysed and compared to the Base Case building. This chapter identified the benefits of the developed early design stage program and the research also highlighted some short falls and limitations with the simulation program.

Carrying out this research was extremely beneficial and a worthwhile educational project. This adverse effect that buildings and their services have on the environment is of very real concern in today's climate. The development of this early design stage program is an excellent tool in which good design strategies and approaches can be adopted to tackle and reduce the buildings and its services effect on the environment.

However the author believes that more research work is required on this program. Other environmental issues could be included and developed into the program, such as green house gases emissions such as carbon dioxide emissions, life cycle analysis and passive day lighting approaches. The author recognises that one of the benefits of the program is that the answers are produced quickly. The addition of further calculations to the program will add time to the retrieval of the results. Nevertheless, as computer power increases and the possible improvement of the computer algorithms within the program software, it should be possible that the calculation time for dynamic simulations will shorten.

Simulation programs often require more user time with regard to the amount of information inputted. As this program is fully integrated with other design programs, the overall design time will not be substantially increased, as there is a large amount of sharing of information between programs. There is detailed database of construction and occupancy profiles. This facilitates ease of inputting the data for the building.

The research in this thesis identified the required information by building designers at the early design stage program. It is clear that the current version of the program provides this information quite adequately, arguably to the benefit of the design team, client and the environment.

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APPENDIX A

Simulation Programs of the Market

Building Energy Simulation Software Design Tools

Program Name	Adeline
Brief Description	Adeline is an integrated lighting design computer tool developed by an international research team within the framework of the International Energy Agency (IEA) Solar Heating and Cooling Performance Task 12.
Expertise Required	Average level of PC computer literacy; understanding of basic lighting concepts
Users	First distributed in late 1994. Architects, lighting designers, researchers, engineers.
Used By	Architects, lighting designers, researchers, engineers.
Input Requirements	Geometry and surface characteristic codes input using 3-D CAD (SCRIBE Modeler); analysis runtime parameters (e.g., geographic location, time of year, sky conditions) entered via graphic user interface dialog boxes.

Output	Various graphic displays of interior illuminance levels, including 3-D renderings; also preformatted text files containing detailed analysis results
Computer Platform	PC-compatible, 386 or higher, with math coprocessor; DOS 3.0 or higher.
Programming Language	Various modules are written in C, FORTRAN, and other languages.
Advantages	3-D CAD input; complex geometry allowed; accurate daylighting and electric lighting calculations; graphic display of analysis results.
Disadvantages	Non-standard (US) CAD; some module integration rough spots; requires hand-off of text files for whole building analysis.
Availability	Commercially Available

Program Name	ASEAM
Brief Description	Evaluation of high-potential, cost effective energy efficiency projects in existing Federal buildings; calculates results that are within 4-5% of DOE-2 annual energy results; using quick input routines, permits evaluation of a 10,000 ft2 building in about ten minutes. ASEAM (A Simplified Energy Analysis Method) Version 5.0 automatically creates DOE-2 input files. The FEMP Architects and Engineers Guide to Energy Conservation in Existing Buildings (published November 1990) uses ASEAM as a primary example of how software can be used in over 180 retrofit projects.
Expertise Required	One day workshop recommended; designed to be used by non-engineers with minimal training.
Users	Several hundred.
Used By	US Federal energy personnel.
Input Requirements	Building type and location, outside dimensions, percent glazing, usage patterns, number of floors, central systems and plant.
Output	Average monthly and annual energy savings from retrofits, taking into account all interactive effects using parametric analysis for optimisation
Computer Platform	PC-compatible, 286 minimum, with math coprocessor preferred.
Programming Language	C

Advantages	Currently allows an engineer to easily perform very sophisticated whole building energy analysis (calibrates to utility data using Lotus macros, does parametric analysis on dozens of energy conservation opportunities).
Disadvantages	Should have the same analytical process fully automated for less sophisticated users.
Availability	Commercially Available

blast

Program Name	BLAST
Brief Description	Performs hourly simulations of buildings, air handling systems, and central plant equipment in order to provide mechanical, energy and architectural engineers with accurate estimates of a building's energy needs. The zone models of BLAST (Building Loads Analysis and System Thermodynamics), which are based on the fundamental heat balance method, are the industry standard for heating and cooling load calculations. BLAST output may be utilised in conjunction with the LCCID (Life Cycle Cost in Design) program to perform an economic analysis of the building/system/plant design.
Expertise Required	High level of computer literacy not required; engineering background helpful for analysis of air handling systems.
Users	Over 500.
Used By	Mechanical, energy, and architectural engineers working for architect/engineer firms, consulting firms, utilities, federal agencies, research universities, and research laboratories.
Input Requirements	Building geometry, thermal characteristics, internal loads and schedules, heating and cooling equipment and system characteristics. Readable, structured input file may be generated by HBLC (Windows) or the BTEXT program.

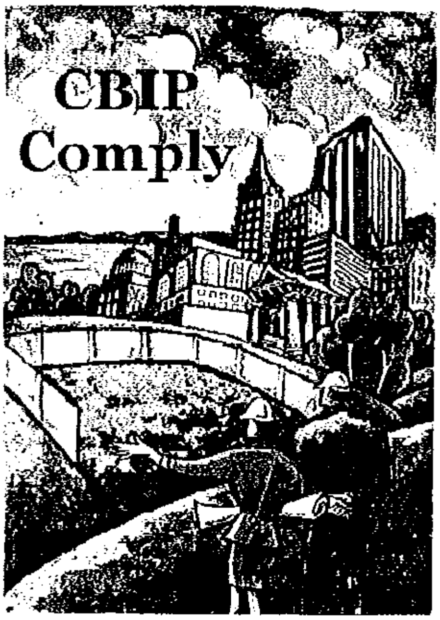
Output	More than 50 user-selected, formatted reports printed directly by BLAST; also the REPORT WRITER program can generate tables or spreadsheet-ready files for over one hundred BLAST variables.
Computer Platform	PC-compatible, 386 or higher; HP/Apollo. Source code is available and has been successfully compiled on most UNIX workstations.
Programming Language	FORTRAN
Advantages	: PC Format has Windows interface as well as structured text interface; detailed heat balance algorithms allow for analysis of thermal comfort, passive solar structures, high and low intensity radiant heat, moisture, and variable heat transfer coefficients -- none of which can be analysed in programs with less rigorous zone models.
Disadvantages	High level of expertise required to develop custom system and plant models.
Availability	Commercially available

Program Name	Building Design Advisor
Brief Description	Software environment that supports the integration of multiple building models and databases used by analysis and visualisation tools, through a single, object-based representation of building components and systems. BDA (Building Design Advisor) acts as a data manager and process controller, allowing building designers to benefit from the capabilities of multiple analysis and visualisation tools throughout the building design process. BDA is implemented as a Windows-based application. The 1.0 version has links to a Schematic Graphic Editor and two simplified simulation tools, one for daylight and one for energy analyses.
Expertise Required	Knowledge of Windows applications.
Users	200.
Used By	Architects and engineers, in early design phases.
Input Requirements	Graphic entry of basic building geometry and space arrangements. Default descriptive and operational characteristics can be edited by user.
Output	User-selected output parameters displayed in graphic form, including 2-D and 3-D distributions.
Computer Platform	PC-compatible, Windows 95/98/NT, 30 megabytes of hard disk space.
Programming	C++

Language	
Advantages	Allows comparison of multiple design solutions with respect to multiple descriptive and performance parameters. Allows use of sophisticated analysis tools from the early, schematic phases of building design. Does not require user to have in-depth knowledge to use linked tools for energy, daylighting and other analyses.
Disadvantages	Version 1.0 is linked to simplified tools for daylight and energy analyses.
Availability	Version 1.0 available on the web.

Program Name	BUS++
Brief Description	New generation platform for building energy, ventilation, noise level and indoor air quality simulations. A network assumption is adopted, and BUS++ allows both steady-state and dynamic simulations on a desired level of accuracy. BUS++ includes modern solution routines and has passed the most commonly used rigorous air flow and heat transfer test cases. However, only a limited number of special applications are completed.
Expertise Required	Special expertise needed for utilising all potential calculation features. Common knowledge of building components needed for using special applications with graphical user interfaces.
Users	20 users in VTT Building Technology and other companies in Finland.
Used By	R&D, scientists, designers, education
Input Requirements	Reads process information from an ASCII input data file. Graphical, dialog based user interfaces are available for special applications only.
Output	ASCII output files for pressure distribution, air flow rates, node temperatures and contaminant levels. Graphical output for special applications and demo versions only.
Computer Platform	PC compatible (Windows 95/NT).

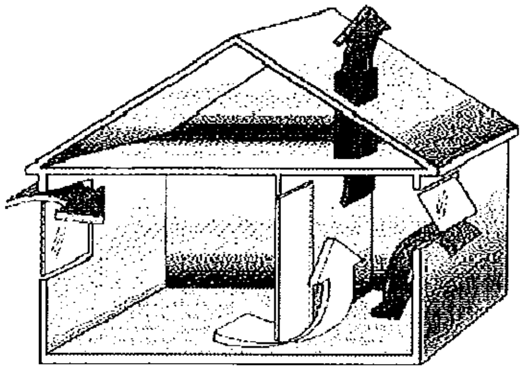
Programming Language	C++
Strengths	Highly flexible simulation environment and effective solution routines together offer a productive foundation for both development of a general simulation toolbox and tailoring applications for special needs.
Advantages	Testing and development are still ongoing. BUS++ does not include facilities for CFD simulations.
Disadvantages	Due to early stage of development, BUS++ is not generally available, contact VTT for more information.



Program Name	CBIP Comply
Brief Description	CBIP Comply, a derivative of the NECB Comply software, is designed to demonstrate and document compliance with the requirements of the Commercial Building Incentive Program (CBIP) using the computer performance approach. The Commercial Building Incentive Program is offered by the Office of Energy Efficiency of Natural Resources Canada to building owners and developers for the design and construction of new commercial and institutional buildings which use 25% less energy than similar buildings that just meet the requirements of the MNECB. CBIP Comply may also be used to perform non-compliance energy analyses and thus to predict the annual energy consumption of a building and to assess the impact of design changes to the building. CBIP Comply calculations are based on an approved version of DOE-2.1E.

Expertise Required	Basic understanding of Windows. Knowledge of building modelling. Engineering background helpful but not required.
Users	20
Used By	Mechanical, building, energy engineers and architects working for consulting firms, building owners and/or designers,. Building and energy-code verifiers. CBIP application reviewers.
Input Requirements	Basic information, location and MNECB administrative region, floor, wall, roof and glazing areas, construction assemblies and glazing types, characteristics of building's HVAC, lighting and service water heating systems.
Output	Energy consumption of proposed and MNECB reference building. Summary and detailed compliance reports.
Computer Platform	PC-compatible, Windows NT or Windows 95/98 operating system, IBM 486 or Pentium 75 with at least 16 MB RAM, 40 MB free disk space, SVGA monitor with minimum 800 x 600 resolution.
Programming Language	Borland C++
Advantages	CBIP Comply automatically generate a reference building to verify compliance to CBIP requirements using the performance path approach. CBIP Comply can also be used in non-compliance mode to predict a building's annual energy consumption. User-friendly interface and on-line help. Includes default libraries of common building plants, systems, construction assemblies and materials,

	lighting elements, fenestration and operating schedules.
Disadvantages	Equipment sizing and energy cost calculation capabilities have not been included with the first release.
Availability	CBIP Comply demonstration version and installation instructions can be downloaded from the web site.



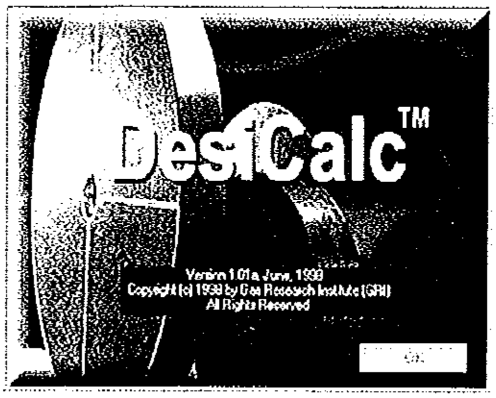
Program Name	COMIS (Conjunction of Multizone Infiltration Specialists)
Brief Description	Air flow distribution model for multizone structures; takes wind, stack and HVAC into account; allows for crack flow, flow through large openings, and single-sided ventilation. Includes pollution transport model.
Expertise Required	Low-level computer skills required to install program; basic HVAC knowledge necessary.
Users	More than 100 in 15 countries.
Used By	Architects, HVAC engineers, physicists.
Input Requirements	Air-flow network, operating schedule, weather data; interactive input program (IISiBat) available.

Output	Preformatted hourly data; user designs reports; graphical output available.
Computer Platform	PC-compatible; source code available for implementation on UNIX-computer; IISiBat graphical interface available for Windows 95.
Programming Language	FORTRAN
Advantages	Detailed analysis with user-defined schedules; takes many flow paths into account;well documented; has been validated by the International Energy Agency's Energy Conservation in Buildings and Community Systems Program, Annex 23 on Multizone Air Flow Modeling. Graphical user interface, IISiBat, allows for rapid development of input file.
Disadvantages	Nodal model; no CAD-like interface for describing the geometries.
Availability	Commercially Available

DEROB-LTH

Program Name	DEROB-LTH
Brief Description	Design tool used to explore the complex dynamic behaviour of buildings for different designs. The behaviour is expressed in terms of temperatures, heating- and cooling loads and different comfort indices. The form of the building can be modelled in a flexible way. The model for assessing the diffuse solar insolation on building surfaces is detailed and includes the influence of different types of shading devices. The window model has been improved and calculates properties for a window package in an accurate way. The simulation uses a time step of one hour and calculates values in response to hourly values for climatic data, internal loads and airflow's.
Expertise Required	An overall knowledge of the influence of different design parameters on the thermal behaviour of a buildings.
Users	20
Used By	Students, researchers and energy consultants
Input Requirements	Building geometry, thermal properties, internal loads and schedules, heating and cooling equipment and schedules, air flows and schedules. Properties for building elements are supported by a library. Hourly values for climatic data are read from a sequential data file.
Output	Lists, MS Excel- ready files, surface diagrams to show comfort

	indices
Computer Platform	PC- compatible, 486 or higher, MS Windows 95 / MS Windows NT.
Programming Language	FORTRAN, Visual Basic
Advantages	DEROB-LTH has an user-friendly interface. The building form can be modelled in a flexible way. Solar insolation is calculated in detail. The influence of shading devices on diffuse solar insolation on building surfaces is calculated according to a detailed shading model. Window packages can be modelled on different levels of detail.
Disadvantages	The HVAC part of the program is still strongly simplified. The report facility should be further improved.
Availability	DEROB-LTH is available under research and commercial license from the Department of Building Science.



Program Name	DesiCalc
Brief Description	Allows users to easily run hour-by-hour simulations to compare the energy needs and costs of using desiccant-based equipment with those of competing electric air-conditioning equipment. The tool provides templates for 11 building types and annual weather data sets for 236 U.S. locations. The tool is fast, user friendly, and Windows-compatible. This software, available on CD-ROM, projects potential energy and cost savings provided by using desiccant-based equipment.
Expertise Required	General knowledge of commercial air conditioning system design and energy analysis. Knowledge of desiccant system application is helpful. No computer programming experience is required.
Users	Approximately 60 to date.
Used By	Design professionals, energy service companies, utilities and HVAC equipment manufacturers and sales reps.
Input Requirements	Location, energy rate data, application type and size, comfort control setpoints, internal loads and ventilation parameters, and equipment parameters and control options.

Output	Reports and charts. Reports include job description, building type characteristics, location and design weather, user-defined electric cooling and desiccant dehumidification equipment characteristics, annual energy usage and cost, summary of key calculated desiccant dehumidifier performance variables, monthly cooling and heating loads, monthly electric and gas energy consumption by equipment type, and monthly electric and gas cost components. Available charts include humidity control bins, monthly electric energy use, electric demand, electricity costs, gas energy use, gas costs, energy costs, and annual energy costs.
Computer Platform	Minimum 486DX2/66 CPU-based PC with CD-ROM drive operating in the MS Windows environment (3.1, 95, 98 or NT). A Pentium PC running Windows 95/98 is recommended.
Programming Language	Visual Basic with DOE-2.1E macros and templates.
Advantages	Easy to use, quick hourly energy analysis using DOE-2.1E as the simulation engine. Includes templates for 11 typical commercial building types, user-modifiable gas and electric rates, and TMY2 weather data for 236 U.S. locations.
Disadvantages	DesiCalc is not a design tool. The building models from which energy costs are computed are representative of the various application types. Users have limited access to building characteristics and HVAC system variables.
Availability	Commercially Available

Program Name	DOE-2
Brief Description	Hourly, whole-building energy analysis program calculating energy performance and life-cycle cost of operation. Can be used to analyse energy efficiency of given designs or efficiency of new technologies. Other uses include utility demand-side management and rebate programs, development and implementation of energy efficiency standards and compliance certification, and training new corps of energy-efficiency conscious building professionals in architecture and engineering schools.
Expertise Required	High level of computer literacy required; recommend 5 days of formal training in basic and advanced DOE-2 use.
Users	800 user organisations in U.S., 200 user organisations internationally; user organisations consist of 1 to 20 or more individual
Used By	Architects, engineers in private A-E firms, energy consultants, building technology researchers, utility companies, state and federal agencies, university schools of architecture and engineering.
Input Requirements	Hourly weather file plus Building Description Language input describing geographic location and building orientation, building materials and envelope components (walls, windows, shading surfaces, etc.), operating schedules, HVAC equipment and controls, utility rate schedule, building component costs. Available with a range of user interfaces, from text-based to interactive/graphical windows-based environments.

Output	20 user-selectable input verification reports; 50 user-selectable monthly/annual summary reports; user-configurable hourly reports of 700 different building energy variables.
Computer Platform	PC-compatible; Sun; DEC-VAX; DECstation; IBM RS 6000; NeXT; 4 megabytes of RAM; math coprocessor; compatible with UNIX, DOS, VMS.
Programming Language	FORTRAN
Advantages	Detailed, hourly, whole-building energy analysis of multiple zones in buildings of complex design; widely recognised as the industry standard.
Disadvantages	High level of user knowledge and computer literacy required.
Availability	Commercially Available

Program Name	Energy Scheming
Brief Description	A design tool to help the user create an energy-efficient building; provides loads analysis for 24 hours for each of 4 seasonal evaluation days. Input is graphical and intuitive and is designed to support the earliest phases of design, where energy considerations can have the most impact.
Expertise Required	Understanding of basic concepts of energy design; familiarity with the Macintosh interface is helpful.
Users	More than 600.
Used By	Architectural professionals, students, and building designers.
Input Requirements	Building drawing can be scanned, imported from a CAD package, or drawn within Energy Scheming. User takes off areas and associates these to specifications that describe materials, orientation. Includes walls, floors, roofs, windows, mass, occupants, equipment, electric and daylighting. Buildings schedules can be customised; four climates provided, user can define own climates as well. Exterior or interior shades, cross and stack ventilation, and mass strategies supported.
Output	Loads displayed in graph as well as text form; printed Energy

	Performance Report includes both graphic and text description of all aspects of the building elements and loads.
Computer Platform	Macintosh SE or better.
Programming Language	MPW C
Advantages	Graphical input and output support designer's visual thinking; easy to learn.
Disadvantages	Single zone; does not do HVAC; does not do annual energy summary.
Availability	

Program Name	ENERPASS
Brief Description	Detailed building energy simulation program for residential and smaller commercial buildings. ENERPASS calculates the annual energy use for space heating, cooling, lighting, water heating and fan energy. The calculations are performed on an hourly basis using hourly measured weather data. ENERPASS can model up to seven building zones and provides hourly temperature and humidity predictions for each zone. A wide range of HVAC systems can be modelled including make-up air units, heat recovery ventilators, rooftop units, VAV, four-pipe fan coil, and dual duct. The program uses full screen data entry in an easy-to-use format. A typical building model can be generated in one to two hours. In IEA validation studies ENERPASS results compare favourably with other hourly based computer programs.
Expertise Required	A general understanding of building construction is required.
Users	Hundreds of builders, architects and researchers primarily in North America.
Used By	Building designers and specifies can use ENERPASS to design more energy efficient buildings.
Input Requirements	Users must enter areas and R-values of walls, windows, etc and the characteristics of the HVAC and lighting systems. The program includes libraries of standard construction assemblies and equipment.
Output	Annual energy use and cost; includes histograms of temperature,

	humidity and light levels. Hourly results can also be displayed.
Computer Platform	PC-compatible 386 or higher, DOS, Windows 3.1 or 95.
Programming Language	C and FORTRAN
Advantages	Easy and quick data entry. Hourly calculation of results.
Disadvantages	The program is limited to seven zones and cannot handle large complex buildings such as hospitals.
Availability	A demo version can be download from their web page.

ENERGY - 10

Program Name	Energy-10
Brief Description	Design tool for smaller residential or commercial buildings that are less than 10,000 ft2 floor area, or buildings which can be treated as one or two-zone increments. Performs whole-building energy analysis for 8760 hours/year, including dynamic thermal and daylighting calculations. Specifically designed to facilitate the evaluation of energy-efficient building features in the very early stages of the design process.
Expertise Required	Moderate level of computer literacy required; two days of training advised.
Users	More than 1,000 users world-wide
Used By	Building designers, especially architects; also HVAC engineers, utility companies, university schools of architecture and architectural engineering.
Input Requirements	Only 4 inputs required to generate two initial generic building descriptions. Virtually everything is defaulted but modifiable. User adjusts descriptions as the design evolves, using fill-in menus, including utility-rate schedules, construction details, materials.
Output	Summary table and 20 graphical outputs available, generally

	comparing current design with base case. Detailed tabular results also available.
Computer Platform	PC-compatible, Windows 3.1/95/98, Pentium processor with 16 megabytes of RAM is recommended.
Programming Language	Visual C++
Advantages	Fast, easy-to-use, accurate. Automatic generation of base cases and energy-efficient alternate building descriptions; automatic application of energy-efficient features and rank-ordering of results; integration of daylighting thermal effects with thermal simulation; menu display and modification of all building-description and other data.
Disadvantages	Limited to smaller buildings and HVAC systems that are most often used in smaller buildings.
Availability	Additional information and examples also on the Energy-10 web site

Program Name	ESP-r
Brief Description	Allows an in-depth appraisal of the factors which influence the energy and environmental performance of buildings. The ESP-r system has been the subject of sustained developments since 1974 with the objective of simulating building performance in a manner that: a) is realistic and adheres closely to the actual physical system, b) supports early-through-detailed design stage appraisals, and c) enables integrated performance assessments in which no single issue is unduly prominent. ESP-r attempts to simulate the real world as rigorously as possible and to a level which is consistent with current best practice in the international simulation community. By addressing all aspects simultaneously, ESP-r allows the designer to explore the complex relationships between a building's form, fabric, plant and control. ESP-r is based on a finite volume, conservation approach in which a problem (specified in terms of geometry, construction, operation, leakage distribution, etc.) is transformed into a set of conservation equations (for energy, mass, power, etc.) which are then integrated at successive time-steps in response to climate, occupant and control system influences. ESP-r comprises a central Project Manager around which is arranged support databases, a simulator, various performance assessment tools and a variety of third party applications for CAD, visualisation and report generation.
Expertise Required	Understanding of thermo-physical processes in buildings.
Users	Hundreds of users, primarily in Europe.

Used By	Engineers, researchers, energy consultants.
Input Requirements	Building geometry can be defined either using CAD tools or in-built facilities. ESP-r is compatible with the AutoCAD and Xzip CAD tools which can be used to create a building representation of arbitrary complexity. Constructional and operational attribution is achieved by selecting products and entities from the support databases and associating these with the surfaces and spaces comprising the problem. As required, component networks can be defined to represent, for example, HVAC systems, distributed fluid flow (for the building-side air or plant-side working fluids) and electrical power circuits.
Output	Results analysis modules are used to view the simulation results and undertake a variety of performance appraisals. Tools are provided to enable the construction of an Integrated Performance View or IPV which summarises performance over a range of relevant criteria. Changes to the model parameters can then follow depending on these appraisals. The range of analyses are essentially unrestricted, allowing interrelation of the different performance indicators, and translation of these indicators to design changes.
Computer Platform	X-Windows, Solaris, Sun/OS.
Programming Language	C++ and FORTRAN
Advantages	In addition to state of the art standard simulation features, powerful capability to simulate many innovative or leading edge technologies

	including daylight utilisation, combined heat and electrical power generation via photovoltaic facades, CFD, multi-gridding, and complex control systems.
Disadvantages	Specialist features require knowledge of the particular subject. Although robust, ESP-r is still primarily intended as a research tool.
Availability	ESP-r is available under research (cost-free) and commercial (low cost) license from the University of Strathclyde. In both cases source code is made available..

Program Name	EZDOE
Brief Description	An easy to use IBM PC version of DOE-2. EZDOE calculates the hourly energy use of a building and its life-cycle cost of operation given information on the building's location, construction, operation, and heating and air conditioning system. Using hourly weather data and algorithms developed by Lawrence Berkeley National Laboratory, EZDOE takes into account complex thermal storage effects of various building materials. In addition, it can also accurately simulate the operation of all types of heating and cooling plants including ice water thermal storage and cogeneration systems. Up to 22 different air handling systems each with multiple control options are supported. The types of heating and cooling plants allowed is nearly infinite as thousands of combinations of chillers, boilers, furnaces, pumps, and cooling towers are allowed. There is even provision for user defined plants and performance curves. The economic analysis capabilities of EZDOE allow for complex utility rate structures, fuel costs, initial equipment costs, replacement costs, and annual costs for non-plant items and baseline data for comparative runs. A large library of over 230 hourly weather data files is available for EZDOE. One weather data file of your choice is supplied with EZDOE while others are available at additional cost.

Expertise Required	Basic familiarity with building geometry and HVAC systems is desirable but not absolutely necessary.
Users	Unknown.
Used By	Architects and engineers involved in new and retrofit building projects, researchers, equipment and utility marketers.
Input Requirements	Features full screen editing with simple
Output	Offers all of the standard reports as the workstation version of DOE-2. These reports can be viewed on the screen, stored in a disk file, or printed.
Computer Platform	Requires an 486 or higher IBM PC compatible.
Programming Language	N/A
Advantages	Implements DOE-2 in an easy-to-use full screen editing environment with dynamic error checking. All input data is checked at the time of entry so that no improper data can be entered. If you have a question about what the program is requesting, you can press the "?" or F10 key to obtain additional help explanations. All data is saved to disk as it is entered. Four major types of data are requested: Loads, Systems, Plants, and Economics. Load data contains the building and space dimensions, wall and glass orientations, construction materials, people, lighting, equipment,

	and much more. The Systems data involves all information concerning air handling and heat delivery systems. VAV, constant volume, PTAC, dual duct, two/four pipe fan coils, and radiators are just a small sampling of the many system types supported by EZDOE. The Plant data concerns the cooling and heating equipment such as chillers, boilers, cooling towers and pumps. The Economic section considers initial, annual, cyclical, replacement, and operating costs.
Disadvantages	Limited to capabilities within the DOE-2 program.
Availability	Demonstration copy available for download from the web site, or order a copy, with complete documentation. Demonstration copies retain all the functionality of the full programs, they are just limited on the size of the project data that can be entered.

Program Name	Ergon
Brief Description	Permits studies into running costs, tariff analysis, CHP feasibility studies, primary energy consumption and environmental gas emissions.
Expertise Required	Good technical understanding of energy analysis considerations and a good knowledge of energy consumption parameters
Users	Mainly UK, some in Ireland.
Used By	Engineers, researchers, energy consultants.
Input Requirements	Geometrical building data may be imported from a range of CAD systems via customised links or DXF files. Geometrical models may alternatively be entered using facilities within the Virtual Environment
Output	Negotiated tariffs and tariff cost analysis Combined Heat and Power feasibility studies based upon the site power and thermal demand profiles. Breakdown of fuel requirements & gaseous emissions
Computer Platform	SCO Unix, Windows-NT
Programming Language	C, C++,
Advantages	Wide range of feasibility studies available.

Disadvantages	
Availability	Available through IES <Virtual Environment>simulation software tools.

Program Name	FEDS
Brief Description	Provides a comprehensive method for quickly and objectively identifying energy improvements that offer maximum savings. FEDS (Facility Energy Decision System) makes assessments and analyses energy efficiency of single buildings, multiple buildings, or all buildings of an entire facility. It provides an easy-to-use tool for identifying energy efficiency measures, selecting minimum life-cycle costs, determining payback, and enabling users to prioritise retrofit options.
Expertise Required	Minimal using readily available information. Requires two or more hours depending on number of buildings.
Users	Over 600.
Used By	Energy and facility managers, architects-engineers, utility planners, building technology researchers, educators, federal agencies, and energy consultants.
Input Requirements	Location, building types, operating hours, age, square footage, fuels used by facility, energy price data, financial incentives are required. Numerous engineering parameters are optional.

Output	Fuel-neutral analysis with full life-cycle costing of retrofit options (ECMs) for the on-site buildings. Output data includes energy and cost savings, emissions reductions, and a wide range of economic measures.
Computer Platform	PC-compatible, operating Windows 3.1x or Windows 95. A 486/DX processor or higher is recommended.
Programming Language	
Advantages	Does not require input of engineering parameters. Energy/economic analysis. Models peak demand. Optimises retrofit opportunities. Performs analysis that meets unique Federal needs. Accepts unlimited number of buildings. Engineering and economic parameters provided are user adjustable.
Disadvantages	: Not a buildings design tool.
Availability	Commercially Available

Program Name	FSEC 3.0
Brief Description	A detailed whole-building and component analysis program; includes heat, moisture and contaminant transport simulation. Both detailed and simplified moisture models are available. Recent enhancements include models for radon transport and pressure driven airflow's in buildings and systems. Primarily developed as a tool for research, design and development of innovative cooling and dehumidification systems. Developed by the Florida Solar Energy Centre, FSEC 3.0 uses the finite element method for distributed modelling. Recently enhanced to include radon transport and entry in soil/slab/building. User-definable routines provide the flexibility to accommodate various user equations, options and systems.
Expertise Required	Requires knowledge of numerical methods and governing equations being solved; high-level computer literacy.
Users	25-30
Used By	Engineers, researchers, educators; primarily a research tool.
Input	Requires ASCII input file; requires complete building details

Requirements	including, layout, material properties, transport coefficients, equipment performance, weather data.
Output	As requested by user.
Computer Platform	VAX/VMS or PC-compatible.
Programming Language	FORTRAN 77
Advantages	Extremely detailed analyses possible; allows up to 250 user-defined governing equations to be incorporated. Excellent platform for integrating with other models/software.
Disadvantages	Weak input processor; no error checking/messages; requires high level knowledge of numerical methods and equations.
Availability	Available on 1600 BPI tape or 3.5" diskette at nominal cost from technical contact. Continually being developed and upgraded.

Green Building Advisor

Program Name	Green Building Advisor
Brief Description	Identifies the specific design strategies that can improve the environmental performance, cost-effectiveness, and healthiness of a building. The strategies are selected by the Green Building Advisor (GBA) based on information provided by the user about a project, such as the location, type and size of building, characteristics of the site, etc. The Version 1.0 release of GBA includes over 700 strategies. The selected strategies are each designated 'strongly recommended' or 'moderately recommended', and are grouped into environmental topics (energy, water, or indoor environment) and subtopics for easier browsing. GBA provides several screens of information on each strategy, including links to detailed green building case studies that illustrate the strategies in context. The 18 case studies in version 1.0 are well-illustrated, representing a range of building types and climates. Each strategy also has links to resources for additional information (books, periodicals, Web sites). Some background references are included in the program, while others must be accessed separately. Hotlinks provide direct access to references on the Internet.
Expertise	: No expertise needed. Basic knowledge of building design and

Required	environmental issues is helpful.
Users	Newly released in January 1999.
Used By	Architects and other designers, educational institutions, building contractors, facility managers, building owners.
Input Requirements	Project location (within U.S.) and about 25 variables (all optional) selected from pull-down menus.
Output	Lists of relevant green building strategies, sorted by level of recommendation, environmental topic, and subtopic. Includes details on each strategy, with links to case studies, information resources. Strategies can also be filtered by first cost, life-cycle cost, difficulty, and appropriate design phase. Strategy lists and details can be exported for use in creating a project-specific report.
Computer Platform	Windows and Macintosh
Programming Language	Macromedia Director
Advantages	Comprehensive database of design strategies, innovative user interface, and its seamless integration of vast amounts of information in various formats. Good learning tool for those inexperienced in green design, and good checklist tool for the more advanced.
Disadvantages	No modelling or simulations for specific quantitative feedback on a project.

Availability	Available commercially

Program Name	HAP v4.0
Brief Description	A versatile system design tool and a powerful energy simulation tool in one package. HAP (Hourly Analysis Program) v4.0 for Windows also provides the ease of use of a Windows-based graphical user interface, and the computing power of Windows 32-bit software. HAP's design module uses a system-based approach which tailors sizing procedures and reports to the specific type of system being considered. Central AHUs, packaged rooftop units, split systems, fan coils and PTACs can easily be designed, as can CAV, VAV, single and multiple-zone systems. The ASHRAE-endorsed Transfer Function Method is used to calculate building heat flow. HAP's energy simulation module performs a true 8760 hour energy simulation of building heat flow and equipment performance. It uses TMY weather data and the Transfer Function Method. Many types of air handling systems, packaged equipment, and plant equipment can be simulated. Costs can be computed using complex utility rates. Extensive, easy to read reports and graphs document hourly, daily, monthly and annual energy and cost performance.
Expertise Required	General knowledge of HVAC engineering principles.
Users	5000 world-wide.
Used By	Practising engineers involved in the design, specification and analysis of commercial HVAC systems/equipment. Instructional tool in colleges and universities. Design/build contractors, HVAC contractors, facility engineers and other professionals involved in

	the design and analysis of commercial building HVAC systems. It can be used for new design, retrofit and energy conservation work.
Input Requirements	Building geometry, envelope assemblies, internal heat gains and their schedules; equipment components, configurations, controls and efficiencies; utility rates.
Output	48 design and analysis reports available to view or print. Design reports provide system sizing information, check figures, component loads, and building temperatures. Simulation reports provide hourly, daily, monthly and annual performance data. Users control the content and format of all graphical reports.
Computer Platform	Windows 95/98/NT compatible PC, Pentium or higher, minimum 32MB RAM, minimum 20 MB hard disk space.
Programming Language	Software is compiled. Source code is not available.
Advantages	HAP balances ease of use with technical sophistication. Technical features are comparable to DOE 2.1; comparison studies with DOE 2.1 have yielded good correlation. The Windows graphical user interface, report features, data management features, on-line help system and printed documentation combine to provide an efficient, easy to use tool.
Disadvantages	HAP is not an effective tool for the research scientist. Because it is designed for the practising engineer, HAP does not permit modification of source code to model one-of-a-kind equipment configurations and control schemes often studied in research situations.

Availability	Commercially Available

Program Name	HEAT2
Brief Description	Two-dimensional transient and steady-state heat transfer within objects that can be described in a rectangular grid. It is well adapted to the following applications within building physics: analysis of thermal bridges, calculation of U-values for building construction parts, estimation of surface temperatures (surface condensation risks), calculation of heat losses to the ground from a house, optimisation of insulation fitting, and analysis of floor heating systems. Arbitrary thermal properties and initial temperatures can be specified. Boundary conditions can vary over time as being periodic, step-wise constant, or step-wise linear. HEAT2 can handle such internal modifications as heat sources, internal boundaries of prescribed temperature, and internal regions containing air or fluid of a given temperature. Pipes with given temperatures or effects may be used. Internal resistance's can be specified. HEAT2 may account for thermal radiation in cavities.
Expertise Required	High level of computer literacy not required; engineering background is required.
Users	Over 1000 in more than 20 countries (about half of them are within universities and research institutes).
Used By	Building physics, mechanical, energy, architect/engineer firms, consulting firms, federal agencies, research universities, and research laboratories.

Input Requirements	Building geometry, thermal characteristics, external and internal loads, heat sources, etc. Input data is given via an integrated menu system. A CAD-like drawing program facilitates input. A figure may be pasted from another program (or scanned) into the pre-processor HEAT2W. The geometry input is made by drawing "on" this figure.
Output	Temperatures and heat flows. Various graphical pictures such as computational mesh and isotherms may be produced. Output data files may also be imported into MATLAB where different plots such as isotherm plots and surface plots may be drawn.
Computer Platform	PC running Windows 95/98 or NT with 16 MB RAM.
Programming Language	PASCAL
Advantages	Well-documented and well-tested program. The time to generate the complete input for a reasonably complicated case is less than 10 minutes after a few hours' experience of the program. Large problems with 60000 numerical cells may be solved.
Disadvantages	Cartesian co-ordinates must be used (sloped boundaries are modelled using 'steps').
Availability	Commercially Available

Program Name	HEAT3
Brief Description	Three-dimensional transient and steady-state heat conduction within objects that can be described in a rectangular grid. HEAT3 can be used for analyses of thermal bridges, heat transfer through corners of a window, heat loss from a house to the ground, to mention a few applications. Arbitrary thermal properties and initial temperatures can be specified. HEAT3 can handle such internal modifications as heat sources and internal boundaries of prescribed temperature.
Expertise Required	Required: High level of computer literacy not required; engineering background is required.
Users	Over 500 (most of them are within universities and research institutes).
Used By	Building physics, mechanical, energy, architect/engineer firms, consulting firms, federal agencies, research universities, and research laboratories.
Input Requirements	Building geometry, thermal characteristics, external and internal loads, heat sources, etc. A three-dimensional figure is drawn that shows geometry, numerical cells, and boundary conditions. The figure may be rotated in space and details of particular interest can be enlarged (zoom).
Output	Temperatures and heat flows. Extensive graphical capabilities: figures showing geometry, numerical mesh, boundary conditions,

	surface or internal temperature field can be rotated in space, and details of particular interest can be enlarged.
Computer Platform	PC running Windows 95/98 or NT with 16 MB RAM (125000 nodes). One million nodes require 48 MB RAM.
Programming Language	32-bit PASCAL
Advantages	Well-documented and well-tested program. For a reasonably complicated case, 10-15 minutes work is sufficient for an experienced user to describe the geometry, the numerical mesh, and the boundary conditions. Fast execution (32-bit code). Large problems with one million computational nodes may be solved on a PC.
Disadvantages	Input data given in a text file (but may be checked by three-dimensional images). Cartesian co-ordinates must be used (sloped boundaries are modelled using 'steps').
Availability	Commercially Available

Program Name	HVACSIM+
Brief Description	Simulation model of a building HVAC (heating, ventilation, and air-conditioning) system plus HVAC controls, the building shell, the heating/cooling plant, and energy management and control system (EMCS) algorithms. The main program of HVACSIM+ (HVAC SIMulation PLUS other systems) employs a hierarchical, modular approach and advanced equation solving techniques to perform dynamic simulations of building/HVAC/control systems. The modular approach is based upon the methodology used in the TRNSYS program.
Expertise Required	High level of computer literacy.
Users	More than 100.
Used By	Building technology researchers, graduate schools, consultants.
Input Requirements	Building system component model configuration, simulation set-up work file, boundary data file, and simulation control data. Weather data and thermal property data of building shell materials are also required, when building shells are included in a simulation.
Output	User-designed reports.
Computer Platform	PC-compatible, with 640 kilobytes of RAM and math coprocessor.

Programming Language	FORTRAN 77
vAdvantages	Dynamic response using variable time-steps; flexibility of model set-up; interactive simulation model generation; simultaneous non-linear equation solving; stiff ordinary differential equation handling.
Disadvantages	High level of user computer literacy required; long calculation time when solving simultaneous equations.
Availability	Commercially Available

HOT2000

Program Name	HOT2000
Brief Description	Easy-to-use energy analysis and design software for low-rise residential buildings. Utilising current heat loss/gain and system performance models, the program aids in the simulation and design of buildings for thermal effectiveness, passive solar heating and the operation and performance of heating and cooling systems.
Expertise Required	Basic understanding of the construction and operation of residential buildings.
Users	Over 1400 world-wide. HOT2000 is used mainly in Canada and the United States with a few users in Japan and Europe.
Used By	Builders, design evaluators, engineers, architects, building and energy code writers, Policy writers. HOT2000 is also used as the compliance software for the Canadian R-2000 Program.
Input Requirements	Building geometry, construction characteristics (above and below grade), HVAC and domestic hot water specifications, geographical location of the house, fuel costs and economic data (optional). The data is entered through a graphical user interface. Many defaults are provided, if the user is not sure of certain values

Output	Reports on the house analysis, weather file, economic and financial conditions and fuel costs are available. The house analysis includes detailed monthly tables, annual heat loss and HVAC load results. A comparison report allows for the display of results of up to 4 house files at once.
Computer Platform	PC compatible, 486 or higher, Windows 95/NT, SVGA monitor with minimum 800 x 600 resolution.
Programming Language	Calculation engine: FORTRAN, interface: Visual C++
Advantages	Performs whole-house energy analysis quickly (
Disadvantages	Cannot size HVAC equipment room-by-room
Availability	Commercially Available

Program Name	HOT2XP
Brief Description	New member of the HOT2000 family of energy analysis software. Its graphical user interface and simplified input make it a quick and easy tool for analysing energy use in houses. However, the underlying engine is that of HOT2000 and thus provides a state of the art analysis.
Expertise Required	Basic understanding of the construction and operation of residential buildings.
Users	New program, over 300 users.
Used By	Renovators, builders, utilities, home inspectors, design evaluators, engineers, architects, building and energy code writers, Policy writers, curious homeowners. HOT2XP is also used as the compliance software for the Canadian EnerGuide for Houses Program.
Input Requirements	Building footprint, construction characteristics (above and below grade), HVAC and domestic hot water specifications, geographical location of the house, and fuel costs. The data is entered through a menu-driven interface. Internal structural libraries provide many defaults. The user can overwrite these defaults and add additional details (i.e. window descriptions), which will increase the accuracy of the analysis.
Output	Graphical Home Owner Reports are available (text and graphics). Technical Reports on the house analysis can also be viewed. These include detailed heat loss by component, monthly tables, HVAC load results, annual heat loss, fuel consumption and costs.

	HOT2XP has a comparison report that allows for the display of results of up to 4 house files, side-by-side. All reports may be output to the screen, to a printer or to a file. The latter can then be loaded into a spreadsheet program.
Computer Platform	IBM 486 or Pentium, minimum 8 MB RAM. The operating system must be Windows 95/98 or Windows NT.
Programming Language	FORTAN and C++, Seagate Crystal Reports
Advantages	An entire house can be entered in half an hour or less. Performs whole-house energy analysis very quickly which can be used to determine annual energy use and can help determine the cost effectiveness of energy efficiency upgrades. Takes into account thermal bridging through studs in assemblies; has a detailed air infiltration model and foundation heat loss model. Heat balances are performed on the basement, main floor and the attic. HOT2XP has a wide selection of HVAC and hot water equipment (including heat recovery ventilators and heat pumps) for five fuel types (natural gas, electricity, oil, propane, wood). Has been validated extensively against hourly simulation programs and monitoring of real houses. The program can be run in English or in French and in metric, Imperial or U.S. units.
Disadvantages	Cannot size HVAC equipment room-by-room or model multi-zone systems. For detailed energy analysis, users are invited to use the more comprehensive HOT2000 (the program on which HOT2XP is based).
Availability	

Program Name	Jasmine
Brief Description	**Jasmine** is the world leading **smoke and fire simulation tool.** For well over a decade the **Fire Research Station (FRS)** have been developing new technology for predicting fire behavior inside buildings and other types of compartment. **Jasmine** is a **CFD** (Computational Fluid Dynamics) tool specifically designed to: • Solve the transient and turbulent fluid dynamic field equations • Combustive chemical reactions equations Predict the heat and mass transfer process associated with the dispersion of combustion products from a fire
Expertise Required	Knowledge of fire and smoke design parameters. Some familiarity required with
Users	Many in UK and Europe
Used By	Engineers and Fire Consultants and Officers
Input Requirements	Geometrical data on building, construction data, occupancy profiles, fire type.
Output	Provides local predictions within the volume of the compartment in 3D and in time e.g • Temperatures, • Densities, • Pressures, • Gas velocities • Chemical compositions.

Computer Platform	SCO Unix, Windows-NT
Programming Language	C, C++,
Advantages	Gives sufficient data on the fuels concerned, also give estimates of visibility's.
Disadvantages	
Availability	Available through IES <Virtual Environment>simulation software tools.

Program Name	Load Express
Brief Description	Calculates detailed HVAC load reports for heating, cooling and airflow capacities. Based on ASHRAE algorithms, you are assured of accurate results and valid designs. The intuitive Windows graphical interface makes Load Express a powerful engineering tool with a very short learning curve. The "rookie" or experienced user can quickly and accurately perform load calculations for small to medium-sized light commercial buildings with confidence. Create project files with Load Express in just 4 easy steps. Select a weather profile, enter simulation parameters, define the zones/rooms in the building and create air handler descriptions. Expandable, built-in libraries of building design parameters streamline your data entry time. Explore different design options using the "Alternative" feature.
Expertise Required	Basic knowledge of HVAC equipment, systems, and terms.
Users	Approximately 750 users world-wide.
Used By	Mechanical systems designers who size and calculate loads for HVAC systems.
Input Requirements	Building design parameters and system configurations.
Output	Print any of the 15 summary reports such as design cooling/heating

	loads (design capacities), psychometric state points, and peak load summaries at building, air handler, or zone level.
Computer Platform	PC-compatible, 486 or higher (Pentium recommended), Windows 3.1 or higher, 16 MB RAM, 10 MB free hard disk space.
Programming Language	Visual Basic
Advantages	The intuitive interface and simplified input methods, with the reliability of ASHRAE calculations, make this program both usable and accurate. Load Express lets you control the level of detail to enter and makes editing any specification painless.
Disadvantages	With the program's focus on load calculations for small commercial jobs, it is limited to 20 zone and 20 system inputs.
Availability	Commercially Available

Program Name	Macroflo
Brief Description	**MacroFlo** allows you to: • Dynamically predict the bulk infiltration • Analyse internal air-flow between zones of the building as a function of buoyancy • Consider mechanical and wind pressure forces, by solving the air leakage network for a building Consequently, you can use **MacroFlo** to: • Simulate the effects of air-flow in and out of a building due to wind and temperature stratification. • The facilities offer the user both a technical and a marketing differentiator
Expertise Required	Knowledge on bulk air movement and modelbuilder
Users	Many in UK and Europe
Used By	Engineers
Input Requirements	Model geometry and construction data and air flow characteristics
Output	Bulk air flow distribution through model and zones within model
Computer Platform	Windows NT, Sco Unix.
Programming Language	C, C++

Advantages	**MacroFlo** also incorporates the effects of a mechanical ventilation plant, and the automatic and manual control of openings such as windows and louvres.
Disadvantages	None
Availability	Available through IES <Virtual Environment>simulation software tools.

Market Manager

Energy Analysis System ™

Program Name	MARKETMANAGER
Brief Description	Models any type of residential, commercial or industrial facility under single or multiple scenarios. With MARKETMANAGER, users can instantly select from libraries of predetermined heating and cooling equipment, HVAC, motors, lighting systems, appliances, pools, process equipment, and other building equipment. It simulates integrated building performance including load, system, and plant calculations modelled on an hourly basis. Standard ASHRAE algorithms are used in heating and cooling load calculations for local weather conditions. Model and evaluate the impacts of different rate structures including TOU, demand charges, load factors, or ratchets. Also compare "what if" scenarios to test performance measures, varying equipment, or alternate rate structures. Then generate reports based on your calculations.
Expertise Required	Energy engineering, energy auditing, or energy management background helpful, regional and private training available.
Users	Over 1200 U.S. and international.
Used By	Energy engineers, performance contractors, energy auditors, and sales engineers.
Input Requirements	: Enter information into a Windows-based interface (Building layout - HVAC, envelope and systems set-up, performance measures, rate

	tariff structures, weather data).
Output	Projected load calculations after applying local weather conditions, utility performance measures, internal gains and other factors. Numerous pre-set and customisable reports and graphs comparing load energy and cost calculations in different scenarios.
Computer Platform	System Requirements - Microsoft Windows (version 3.1, Windows for Workgroups, Windows 95, Windows NT) IBM-compatible 386 or higher.
Programming Language	Borland Pascal/Delphi, Crystal Reports, Graphics Server SDK.
Advantages	Windows graphic interface. Ability to show the affects of an entire building on load calculations and the interaction between lighting, heating, cooling and HVAC equipment. Evaluate "what if" questions by creating and customising different scenarios. Completely automated data import/export. Internal quality control. Easily compare alternative rate tariffs.
Disadvantages	High level of expertise required to model and evaluate complex buildings and facilities.
Availability	Commercially Available

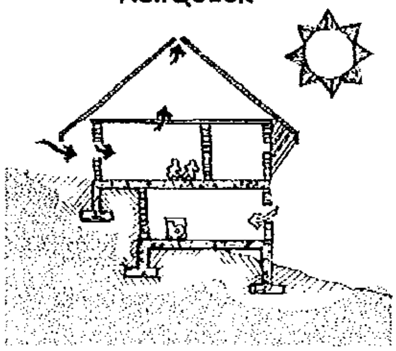
Program Name	Microflo
Brief Description	CFD simulation system for assessing building airflow, air quality and thermal performance. Microflo solves the 3D non-isothermal continuity, momentum, energy and species conservation equations incorporating the k-e turbulence model using finite difference method. Microflo is part of the IES Virtual Environment by which the CFD simulation is coupled dynamically with the full building thermal simulation. The difference in time constants between the building structures and air volumes is handled based on the integrated approach concept
Expertise Required	Virtually no expertise required, although the knowledge of CFD, environmental physics of buildings will be beneficial.
Users	Many in UK and Europe.
Used By	Engineers
Input Requirements	High level of graphical user interface provided for pre-processing including creating 3D models, mesh generating, defining boundary conditions, run monitoring, and batch control.
Output	Extensive graphical post-processing tools provided including displaying results in coloured cut-plane for any selected variables, 3D arrows with variable colouring, animated airflow streamlines, 3D animation, flying through, and photomontage.
Computer Platform	SGI, DEC Alpha, SCO Unix, Linux, Windows-NT

Programming Language	C, C++, Visual Tcl
Advantages	Easy to use. Capable of modelling conjugated heat transfer and airflow, particle dispersion and settling within and outside of buildings of any complexity. The capability is further enhanced by the Integrated Data Model (IDM), which enables the CFD to be integrated as part of the integral simulations of lighting, natural ventilation and building energy.
Disadvantages	Currently only orthogonal objects can be used due to the restriction of Cartesian co-ordinate system. Non-orthogonal objects (e.g. cylinders, sphere, pyramid, polygons) will automatically be discretised into orthogonal prisms during the mesh generation
Availability	Available through IES <Virtual Environment> Simulation Software Tools

Program Name	Micropas4
Brief Description	Easy to use detailed energy simulation program which performs hourly calculations to estimate annual energy usage for heating, cooling and water heating in residential buildings. The program also includes a load calculation to correctly size heating and cooling equipment. Micropas4 has been in wide use in California since the early 1980s as a building energy code compliance tool and is growing in use elsewhere under the Model Energy Code. The last survey showed that about 75% of the single family homes permitted in California used Micropas to determine code compliance. The program is mature, reliable and fast. Micropas4 is fully supported with top notch documentation and complete printouts. The program has a wide range of features to help automate and manage its use.
Expertise Required	Ability to read building plans and an understanding of how the energy efficiency of building features (e.g. R-values, SEER, etc.) are specified.
Users	Over 2000 copies have been sold since 1983, mostly in California and other west coast states. Current users include builders, architects, engineers, mechanical contractors, utilities and energy consultants.
Used By	Although Micropas is a capable general purpose hourly simulation program for energy efficient residential buildings, the main use of the program is to document compliance with residential building energy codes such as the Model Energy Code and California's Title-24 Code.

Input Requirements	Data is required describing each building thermal zone (15 maximum); opaque surfaces (walls, roofs, floors, 100 maximum); fenestration products (doors, windows, skylights, 100 maximum); thermal mass (slabs, etc., 25 maximum); HVAC equipment (heating, cooling, venting, thermostats) and water heating systems (domestic and hydronic heating).
Output	Seven types of clearly formatted printouts are available including summary output, detailed building descriptions, HVAC sizing summary and assembly U-value calculations. For detailed oriented studies, yearly, monthly, daily and hourly table output is available including time-of-use and bin data. Annual and table outputs can be saved in delimited formats suitable for importing into other software for additional analysis and graphics. For studies including many runs, a parametric run generator and databases of run results are available.
Computer Platform	Can run on any DOS, Windows 3.1, Windows 95 or Windows NT based computer. Can run on Macintosh using emulation software.
Programming Language	Microsoft Professional Basic.
Advantages	Mature and reliable program used daily by hundreds of energy consultants in California. Good documentation and good support via toll free number. Can calculate annual energy usage and provide load (sizing) calculations at the same time. Ability to manage multiple runs. Not as complex as DOE-2, not as simple minded as UA type compliance programs.

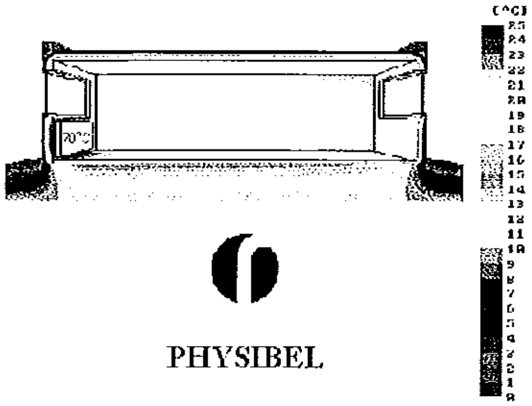
Disadvantages	No detailed modelling of heating and cooling systems is provided--seasonal performance values like AFUEs and SEERs are used.
Availability	Commercially Available



Program Name	NewQUICK
Brief Description	Thermal design and simulation tool capable of calculating loads and energy consumption. NewQuick can predict hourly air temperatures and relative humidities, which makes it a valuable tool in the passive design of building envelopes. Complete load and energy analysis of a building can further be executed in order to design an efficient air-conditioning system (HVAC). The simulation tool executes dynamic thermal calculations for realistic 'real life' temperature and load predictions. The building model integrates natural ventilation, internal load (convective and radiative), occupant load and evaporative cooling models. The simulation tool includes the modelling of external shading devices, interior mass, direct solar heat gains and ground contact surfaces.
Expertise Required	Basic understanding of building construction, with a minimum level of computer skills. A first time user will take approximately 5 minutes to master the preliminary input, do a calculation and view the first results.
Users	An earlier release is used in 45 countries world-wide.

Used By	Engineers, architects, contractors, building designers and research institutions.
Input Requirements	The program gives you two input options: a preliminary design and a detail design option. Only one input screen is used in the preliminary design option for the input of the building structure, climate, internal loads etc. For more detail a series of input screens can be used under the detail design option.
Output	Hourly calculated indoor air temperatures, relative indoor humidities sensible and latent loads. Monthly and yearly energy results are also available. All these results are presented in tables and graphs.
Computer Platform	IBM PC-compatible, 486 or higher; Windows 95 or higher; 8 MB RAM minimum; 10 MB of free disk space.
Programming Language	Pascal for Windows
Advantages	The simulation tool is very user friendly and quick to use even for a first time user. All the surface input data can be selected from a pre-constructed database, which can easily be extended by the user. The same applies for the climate database. A building of any construction, shape and size can be modelled. Unlimited number of zones and surfaces can be entered. The passive thermal and natural ventilation performance of buildings can be investigated with the tool.
Disadvantages	The building model uses a single-zone approach. This implies that no heat exchange exist between different zones in the building. (However set temperatures can be specified on the other side of a

	surface to over come this.)
Availability	Software prices range from $350 for an upgrade package to $950 for a new installation.



PHYSIBEL

Program Name	Physibel
Brief Description	Suite of heat and mass transfer programs: •2-D /3-D steady state heat transfer for building details, thermal bridges, window frames and enclosures: KOBRU86, CYLI86, TRISCO, BISCO, RADCON, KOBRA. •2-D /3-D transient heat transfer for ground heat losses, building details, and efficiency of thermal capacity: SECTRA, VOLTRA. •improved Glaser method for vapour transfer, condensation, and drying: GLASTA. •multi-zone transient heat transfer for heating, cooling, overheating, sunscreens, and passive solar energy: CAPSOL.
Expertise Required	A basic knowledge about heat and mass transfer is sufficient for most programs, but a knowledge in depth of heat transfer mechanisms is helpful to solve complex problems.
Users	More than 300 users in more than 25 countries.
Used By	Universities and (building) research institutes, consulting firms (building physics, architecture, engineering), building industry (manufacturers of insulation, glazing, window frames, building

	components).
Input Requirements	See web site for input requirements of individual programs.
Output	See web site for output data and methods provided from individual programs.
Computer Platform	PC-compatible, 386 or higher, DOS, Windows (95/98/NT).
Programming Language	: C++
Advantages	The simulations based on physical laws (heat balance method) imply physical correctness. In depth analysis of window frames (KOBRU86/BISCO/RADCON). Fast 3-D object description and solution (TRISCO/VOLTRA). In depth simulation of glazing, solar screens, double facades integrated in building simulation (CAPSOL). Input calculation and output are integrated in 1 user interface (all programs). Bitmap graphics can be used to input a 2-D geometry (BISCO). Semi-automatic grid refinement (KOBRU86/SECTRA/TRISCO/VOLTRA). Automatic triangulation (BISCO). Animations of transient heat transfer in building details (SECTRA/VOLTRA) and buildings (CAPSOL). Professional high resolution graphic output (all programs). Databases: materials (all programs), climate databases (transient programs), building details (KOBRA).
Disadvantages	

Availability	Commercially Available

Program Name	Radiance
Brief Description	Advanced lighting simulation and rendering package; calculates spectral radiance values (illuminance & colour) and spectral irradiance (illuminance & colour) for interior and exterior spaces considering electric lighting, daylight and interreflection. Used by architects and designers to predict illumination, visual quality and appearance of design spaces. Used by researchers to evaluate new lighting and daylighting technologies and study visual comfort and similar quantities related to the visual environment.
Expertise Required	High level of computer literacy required; 4 days training, minimum.
Users	Over 200.
Used By	Daylighting, lighting, and architectural designers.
Input Requirements	Geometry and materials of design space, including luminaire photometry and surface reflectance characteristics. Translators are available for DXF, Architrion, and IESNA standard luminaire files. Additional translators have been written by third parties for ArchiCAD and others. A third-party (shareware) CAD program, Vision3D, can prepare Radiance input directly.
Output	Luminance and illuminance values, plots and contours, visual comfort levels, photograph-quality images and video animations.
Computer Platform	UNIX-compatible workstation, e.g. Sun, Silicon Graphics, Hewlett Packard, DECstation, NeXT, Mac II running A/UX; 8- or 25-bit colour display, 20 megabytes of free disk space, 8 megabytes of

	RAM, and math coprocessor recommended. IBM 386-compatible DOS port has been produced but is not currently being distributed.
Programming Language	C (Kernnigan and Ritchie standard)
Advantages	Physical accuracy in a graphics rendering package, reliability and source code availability; arbitrary surface geometry and reflectance properties.
Disadvantages	Lacks a graphical user interface, comprehensive documentation, and examples; too few CAD formats supported.
Availability	Version 2.4 (1994) available free of charge from technical contact via posted tape cartridge (media exchange).

Program Name	REM/Design
Brief Description	User-friendly, yet highly sophisticated, residential energy analysis and code compliance software which eliminates the uncertainty and guesswork from energy design and code compliance decisions. Developed specifically with the needs of homebuilders, remodelers, energy consultants and designers in mind, REM/Design calculates heating, cooling, hot water, lights and appliance loads, consumption and costs for single and multi-family designs in over 250 North American cities. This Windows-based software automatically analyses the energy and economic performance of numerous energy design features including envelope insulation, air leakage control, duct leakage control, active and passive solar systems, heating and cooling equipment, mechanical ventilation and more. In addition to calculating energy performance, REM/Design sizes heating and cooling equipment, and automatically determines compliance with the CABO Model Energy Code (1992, 1993, 1995,1998), ASHRAE 90.2, and the EPA's Energy Star Home program.
Expertise Required	Medium level of computer literacy required.
Users	Used by energy consultants, homebuilders, designers, utilities, weatherisation professionals and researchers throughout the U.S. and Canada.
Used By	Energy consultants, homebuilders, designers, and utility and weatherisation professionals.
Input	Two levels of input: simplified and detailed. Simplified inputs use

Requirements	general building design characteristics (e.g., house type) and built-in algorithms to determine building shell areas and other characteristics. Detailed inputs provide the user greater control over calculational values. Inputs include, opaque wall construction details, window conduction and solar gain values, HVAC efficiencies, duct system characteristics, passive and active solar design features, infiltration rates (measured or estimated).
Output	22 preformatted reports, available for viewing on screen or printing. Reports include energy use, energy cost, normalised energy use, design loads, code compliance, and economic analysis of energy upgrades.
Computer Platform	PC-compatible, Windows 3.1/95/98/NT, 8 MB RAM, 8 MB disk space.
Programming Language	C++
Advantages	Considered one of the easiest residential energy analysis tools to use. One of the only tools that allows side-by-side comparison of two homes, making analysis of energy upgrades easy. Automatic improvement analysis makes automated design optimisation possible. Multi-purpose tool brings together in a single package the capability to perform design optimisation, improvement analysis, compliance analysis and equipment sizing. Explicit modelling of duct conduction and leakage.
Disadvantages	Single zone model. Seasonal methodology cannot predict hourly values. Unsophisticated HVAC equipment modelling.

Availability	Commercially Available

Program Name	ROVE
Brief Description	**ROVE** has the capabilities to: • Provide animations of a 3D model displayed in full colour with textures and realistic lighting effects. • Animation flight control is achieved in real time by letting you have complete control of the viewpoint and other parameters in a full 3D environment • Using the mouse and keyboard you are able to fly through the model as desired. • Predetermined flight paths can be easily defined and the results recorded onto video. **ROVE** can also be used to visualise data from other 4D applications such as CFD and
Expertise Required	Good knowledge of complex model building
Users	Many in UK and Europe.
Used By	Architects and Engineers
Input Requirements	Geometrical and construction data on building, occupancy profile, etc
Output	Animated 3D visualisation of design
Computer Platform	SCO Unix, Windows-NT
Programming Language	C, C++,

Advantages	Excellent method of examining architectural and building design solutions and Complex engineering concepts can be clearly demonstrated using **ROVE**
Disadvantages	Time consuming and takes a long time to generate results
Availability	Available through IES <Virtual Environment>simulation software tools.

Program Name	SPARK
Brief Description	An object-oriented program that allows the user to quickly build models of complex physical processes by connecting calculation modules from an object library. SPARK (Simulation Problem Analysis and Research Kernel) creates an executable simulation program from this network ready to be run by itself or within the DOE-2 simulation engine.
Expertise Required	High level of computer literacy required.
Users	Most existing DOE-2 user organisations; 1000 plus.
Used By	Building technology researchers and energy consultants.
Input Requirements	Calculation modules selected and connected from an object library by using a graphical editor.
Output	Graphical display of results for any simulation variable.
Computer Platform	Sun; Windows-95 and NT.

Programming Language	C
Advantages	Capable of modelling complex building envelopes and building HVAC systems to any level of detail; built-in problem decomposition and reduction techniques reduce execution time; user-selectable time step allows modelling short time-step dynamics; symbolic input of equations avoids programming; graphical editor simplifies model description and construction of customised networks.
Disadvantages	High level of user computer expertise required, user must have C++ compiler to use, program must be linked to DOE-2 for maximum utility.
Availability	Commercially Available

Program Name	Simulex
Brief Description	Simulex • The escape movement of occupants from large, geometrically complex building structures. • Details such as 2D floor plans, and connecting staircases to define the building. • Occupants which are 'placed' into the building either one-by-one or as groups. An 'evacuation' on-screen and 'zoom' in on areas of interest
Expertise Required	Model building skills and knowledge of fire safety design parameters
Users	Many in UK and Europe.
Used By	Building Designers and Fire Safety Officers.
Input Requirements	**Simulex** requires CAD-generated DXF drawings for each floor plan. The user needs to specify the basic dimensions of connecting staircases and the width of final exits. 'People' can be placed into the model on an individual or group-wide basis.
Output	**Simulex** has 3 forms of output :- 1.The visual display of an evacuation as it is simulated (including occupant animation), via different window views and 'zoomed' magnifications, and a notification of the total evacuation time. 2. The playback files which can be created can be reviewed, to animate the evacuation at real-time. The software allows the user to view any point in the building to watch the movement of all individual occupants as they leave the building. 3. A comprehensive text-based document which can be inserted

	into a design report and/or imported into a spreadsheet for further analysis
Computer Platform	The minimum system requirements are a PC running Windows 95, 98, or NT with 32Mb RAM and a 2Gb hard disk. It is recommended that the processor be at least a P2 266 MHz. If thousands of people are to be modelled, then a minimum of a P2-350 would be preferable
Programming Language	C, C++,
Advantages	The algorithms in **Simulex** which model fluctuations in walking speed, side-stepping, body-twisting, overtaking etc. are based on a combination of the results of many video-based analyses of individual movement and the additional results of a number of academic researchers. It is the only computer program to both accurately model the co-ordinate position of each person to a fraction of a millimeter and also the relationship between inter-person distance and changes in walking speed.
Disadvantages	
Availability	Available through IES <Virtual Environment>simulation software tools.

solacalc®

Program Name	solacalc
Brief Description	Simulates passive solar houses by calculating heat losses and solar gains in residential buildings, using interlinked worksheets and very extensive help. Based on New Method 5000, 'solacalc' uses UK climate data to easily and quickly calculate thermal balances and financial analysis. A reference calculation concurrently offers a design comparison without solar features. A Net Present Value calculation provides economic analysis.
Expertise Required	None, but knowledge of spreadsheets and basic building thermodynamics is helpful.
Users	Over 30.
Used By	Architects, Builders, homeowners, technicians in architectural practices, utilities and research establishments
Input Requirements	Building geometry, U values, K values or insulation specifications, heat exchanger flow rates, exterior temperatures, degree days, day lengths, transmitted solar energy, shading factors and internal gains etc. Apart from building geometry, input requirements are available for automatic insertion from internal databases.
Output	22 spreadsheet reports or graph summaries can be printed directly.
Computer	PC-compatible, 386 or higher, running Windows 3.1 or Windows 95.

Platform	
Programming Language	Borland Delphi.
Advantages	Easy and automated version of EU standard method for analysing building thermal performance on a monthly basis. Allows flexible data entry where unusual designs are to be computed. Internet connection is provided for additional data information
Disadvantages	: Currently uses European data. Doesn't provide detailed analysis.
Availability	Shareware with 30 free uses.

Program Name	Suncast
Brief Description	Performs solar shading and insolation analysis and can generate images and animations. Suncast uses sun tracking and hidden surface algorithms to generate and view shadow data for all internal and external surfaces of the model. Suncast generates shadows from any sun position defined by date, time, orientation, site latitude and longitude and can investigate: external obstruction and self-shading of a building; solar mapping through windows; solar radiation on external and internal surfaces; and the effects of changing orientation of the building. &nsbp; Suncast can be used in passive solar design studies and is essential at the planning stage to visualise the effect of the building on surrounding buildings. Suncast has also been used to study problems such as grass growth on sports stadia. In addition, because it is possible to remove surfaces to investigate solar penetration, Suncast has been used to investigate internal design issues from office layouts to positioning of art in museums.
Expertise Required	Familiarity with IES Model Builder
Users	Many throughout UK and Europe
Used By	Architects and Engineers
Input Requirements	3D geometry and site location.
Output	Solar shading images, data, and AVIs

Computer Platform	Unix, Windows NT
Programming Language	C, C++
Advantages	Easy-to-use interface.
Disadvantages	
Availability	Available to IES <Virtual Environment> simulation software tools

Program Name	SuperLite
Brief Description	Daylighting and electric analysis; calculates interior illuminance levels in complex building spaces. Analysis accounts for direct, externally reflected and internally reflected light. Used for residential and commercial applications.
Expertise Required	Average level of computer literacy; understanding of basic lighting concepts.
Users	Approximately 500 world-wide.
Used By	Architects, lighting designers, researchers, engineers.
Input	Space geometry, surface reflectance, aperture transmittance,

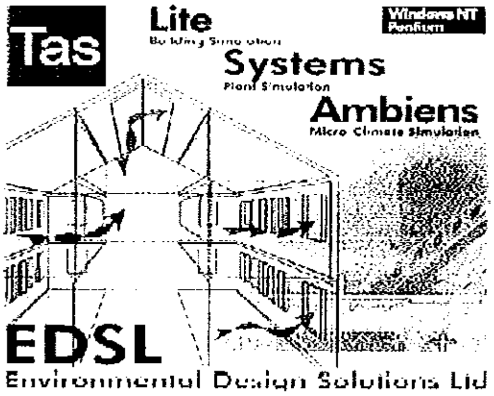
Requirements	luminaire description; input file prepared using standard text or word processor.
Output	Interior point-by-point illuminance levels; preformatted text file.
Computer Platform	PC-compatible, with math co-processor; can be compiled on other platforms.
Programming Language	FORTRAN
Advantages	Complex geometry allowed; variety of sky conditions; illuminance levels on user-oriented planes; daylighting and electric lighting; accurate flux exchange interreflection calculation.
Disadvantages	Only diffuse surfaces; non-interactive input/output.
Availability	Commercially Available

Program Name	System Analyser
Brief Description	Software package for load calculation and energy and economic comparative analysis. System Analyser permits a quick evaluation of virtually any building, system, and equipment combination. Thus, it can be used either as a scoping tool to decide what systems may be appropriate for an initial design, or to get a general feeling of how one system/equipment combination may perform over another. If a certain combination seems especially promising, further analysis can be done by exporting inputs into TRACE 600. The possibilities are endless. And since the program is Windows-based, virtually anyone with minimal HVAC training and experience can use it.
Expertise Required	Basic knowledge of HVAC equipment, systems and terms.
Users	Approximately 800 users world-wide.
Used By	Utility companies and ESCOs who wish to promote alternative cooling strategies; architects and marketing persons who may use this as a powerful, interactive presentation tool; and mechanical engineers who design, size and calculate energy consumption for HVAC systems.
Input Requirements	Building design parameters, system configurations and utility rates.
Output	Print any of the 30 design and analysis reports and graphs such as building loads, equipment energy consumption, economic analysis, yearly cash flows and monthly building load profiles for

	comparisons or presentations.
Computer Platform	PC-compatible 486 or higher (Pentium recommended), Windows 3.1 or higher, 12 MB RAM (16 MB recommended); 13 MB free hard disk space.
Programming Language	CA-Realizer
Advantages	System Analyser is a powerful, interactive presentation tool and it's graphical interface allows even a beginner with minimal HVAC experience to get a complete energy and economic analysis in as little as 10 minutes. The graphs, when printed on a colour printer, provide powerful visual proof for proposals to justify better HVAC systems.
Disadvantages	The program provides reliable comparative system analyses, but lacks some of the extensive details of load and energy components available in the TRACE suite.
Availability	Commercially Available

Program Name	TARP
Brief Description	Hourly, whole-building thermal analysis; calculates energy requirements or temperature drift in building spaces; also computes infiltration's and inter-room airflow's due to wind and stack effects on building openings. Used at the National Institute of Standards and Technology and at several universities for research on building thermal behaviour in cases where air handling system effects need not be considered. TARP (Thermal Analysis Research Program) has been especially useful for passive solar studies.
Expertise Required	High level of computer literacy required. In most uses the program has been modified by the user to study specific thermal processes.
Users	About 50 copies have been distributed.
Used By	University schools of architecture and engineering.
Input Requirements	An ASCII file containing building components and materials, operating schedules, the configuration of building surfaces, geographic location and orientation, design weather data or data from standard weather files.
Output	Hourly, daily, monthly, and/or annual summary reports of user-specified simulation variables.
Computer Platform	PC-compatible, with math coprocessor, 486 or higher preferred.
Programming Language	FORTRAN 77

Advantages	Still represents the state-of-the-art for hourly, multi-zone, heat balance calculations; simultaneous airflow calculations are available in few other programs.
Disadvantages	Lack of air-handling units and plant features prevent use for energy calculations; no longer under active development; minimal support.
Availability	Commercially Available



Program Name	TAS
Brief Description	Software package for the thermal analysis of buildings. TAS includes a 3D modeller, a thermal/energy analysis module, a systems/controls simulator and a 2D CFD package. There are also CAD links into the 3D modeller as well as report generation facilities. It is a complete solution for the thermal simulation of a building, and a powerful design tool in the optimisation of a buildings environmental, energy and comfort performance.
Expertise Required	Qualified Engineer or Architect. Software include comprehensive tutorials. No training courses are required.
Users	250 user sites. Mainly in Europe, some in Canada & Australia.
Used By	Building services engineers and architects.
Input Requirements	A 3D CAD front-end allows building geometry to be input. Geometric data can be entered from other CAD packages. Comprehensive databases on thermal properties of materials, climate data, occupation schedules, plant characteristics. a graphical interface makes for efficient data entry and modification.

Output	Information is provided on comfort conditions, plant sizing, energy use and natural ventilation. There is also a CFD section of microclimate variation. There are pre-formatted inputs and output. all simulation data can be exported to other packages such as Microsoft Excel, Word, Publisher etc. for customised report preparation.
Computer Platform	Windows NT 4.0 on Pentium machines.
Programming Language	C++
Advantages	Excellent responsive and accurate tool for concept development.
Disadvantages	Not intended for detailed services layout design.
Availability	Commercially Available

Program Name	ThermoSim
Brief Description	Provides a novel way to experience the effects of dynamic heat flow within a multi layer slab. As a JAVA applet it is free and easy to use. The main features are •interactive visualisation of dynamical temperature changes in structured walls, and comparison of different simulation algorithms. Different wall structures, material parameters, and simulation algorithms can be selected directly on the screen. Its purpose is to give students in engineering and architecture a first feel in the analysis of heat flow processes in buildings.
Expertise Required	None, but a basic understanding of heat transfer and numerical analysis is helpful.
Users	Unknown number of virtual users in the WWW.
Used By	Students in engineering and architecture to supplement textbooks.
Input Requirements	Wall structure, layer width, heat conductance, heat capacity, film coefficients, and the number of grid points can be chosen from various default settings or may be input as numerical values on the screen. A small database with the properties of building materials is included.
Output	Dynamical visualisation of the temperature in the cross section of a multi layer wall.

Computer Platform	ny computer with a world-wide-web browser which supports JAVA.
Programming Language	JAVA
Advantages	High tutorial and educational value. Free and easy to use, no installation required.
Disadvantages	No whole building simulation, no commercial use.
Availability	Available on web.

Program Name	TRACE 600
Brief Description	Lets you model virtually any building, air handling system, heating or cooling equipment, and economic/utility scenario - then helps you quickly compare them. TRACE 600 (Trane Air Conditioning Economics) lets you model virtually any building, air handling system, heating or cooling equipment, and economic/utility scenario - then helps you quickly compare them. The program takes you step by step from basic building parameters, such as geographic location (TRACE 600 includes over 480 global weather profiles), to powerful system modelling, such as ice storage systems. Streamline data entry using extensive pre-built libraries and "master cards." Apply any one of seven different ASHRAE cooling-and-heating-load calculation methodologies, including ASHRAE's Exact Transfer Function Methodology. Design ASHRAE Standard 62 compliance into your occupied spaces. Optimise your cooling tower. Model complex equipment plants including decoupled chiller systems with heat recovery. Analyse the effects of cogeneration, variable-frequency drives, and daylighting.
Expertise Required	Industry knowledge of HVAC equipment, systems and terms; comprehensive training is available.
Users	Approximately 1200 users world-wide.
Used By	Mechanical engineers who design, size and calculate energy consumption for HVAC systems.
Input Requirements	Building design parameters, schedules, system configurations, equipment models and utility rates.

Output	Print any of the 50 design and analysis reports such as system checksums (design capacities), psychometrics, building temperature profiles, equipment energy consumption .
Computer Platform	PC-compatible, 286 or higher, with math coprocessor; DOS 3.1 or higher; 640 KB RAM; 10 MB free disk space for programs, 6-10 MB free disk space for run-time files.
Programming Language	FORTRAN, C, and PASCAL
Advantages	TRACE programs have provided HVAC engineers with accurate and reliable load and energy analysis calculations since 1972. These intricate programs can analyse and compare advanced HVAC technologies and high-efficiency equipment, and perform extensive economic forecasts.
Disadvantages	Due to the power and complexity of TRACE, training is recommended.
Availability	Commercially Available

Program Name	TRNSYS
Brief Description	Modular system simulation software; includes many of the components commonly found in thermal energy systems as well as component routines to handle input of weather or other time-dependent forcing functions and output of simulation results. TRNSYS (TraNsient SYstem Simulation Program) is typically used for HVAC analysis and sizing, solar design, building thermal performance, analysis of control schemes, etc.
Expertise Required	None to use standard package; FORTRAN knowledge helpful for developing new components
Users	1000 US; 2000 world-wide.
Used By	Engineers, researchers, architects.
Input Requirements	TRNSYS input file, including building input description, characteristics of system components and manner in which components are interconnected, and separate weather data (supplied with program). Input file can be generated by graphically connecting components.
Output	Life cycle costs; monthly summaries; annual results; histograms;

	plotting of desired variables (by time unit); online variable plotting (as the simulation progresses).
Computer Platform	Windows 95 and NT for TRNSYS interface programs. (Distributed source code will compile and run on any Fortran platform).
Programming Language	FORTRAN (although unnecessary for the use of standard components).
Advantages	Due to its modular approach, extremely flexible for modelling a variety of thermal systems in differing levels of complexity; supplied source code and documentation provide an easy method for users to modify or add components not in the standard library; extensive documentation on component routines, including explanation, background, typical uses and governing equations; supplied time step, starting and stopping times allowing choice of modelling periods. Version 14.2 moves all the TRNSYS utility programs to the MS Windows platform (95/NT), including a choice of graphical drag-and-drop programs for creating input files, a utility for easily creating a building input file, and a program for building TRNSYS-based applications for distribution to non-users. Web-based library of additional components and frequent downloadable updates are also available to users.
Disadvantages	: No assumptions about the building or system are made (although default information is available) so the user must have detailed information about the building and system and enter this information into the TRNSYS interface.
Availability	Version 14.2, Commercial

Program Name	tsbi3
Brief Description	Easy-to-use and flexible program when evaluating the indoor climate and energy conditions as well as the designing of the heating, cooling and ventilation plants. tsbi3 is a tool for consulting engineering companies, research institutes and others who need to simulate and calculate the thermal working environment, energy consumption, control functions, energy saving measures in buildings and the utilisation of passive solar energy. tsbi3 permits calculation on complex buildings with several (in principle indefinitely many) rooms and zones simultaneously. tsbi3 utilises data from all structures in the thermal evaluation. All depending on the complexity of the building and the systems, a total of 200-400 data, which usually are to be taken direct from the project material, must be given
Expertise Required	Users must have some general knowledge on building design and how buildings behave thermally in order create the building model.
Users	Approximately 200 licences, of which about 150 in Denmark.
Used By	Engineers, researchers and students.
Input Requirements	When using the tsbi3 the building is divided into rooms or zones where materials, building component, equipment and systems used are described as follows: Rooms and zones The net and gross area, net height, distribution of solar radiation, surfaces surrounding the zone as well as equipment and systems in

	the zone. Structures and materials Description of type, density, thermal capacity and thermal conductivity. Walls, floors and roof constructions are built in layers according to the description of the materials. The structures are joined together with the windows and doors to make entire surfaces stating the orientation and slope. Sunshades are defined in relation to the surfaces. Equipment and functions Internal loads (e.g. persons, lighting, equipment, moisture load), natural ventilation (e.g. infiltration, venting), heating and cooling radiators, and ventilation systems. All such "systems" are defined by the physical component as well as how it is controlled and when in function. Central and local ventilation plants Supply and exhaust fans as well as total pressure rise and total efficiency. Units of heat recovery, heating and cooling coils, and humidifiers. Together with the control strategy chosen, these data form the base for calculating the power demand and energy consumption necessary for running the plants. Automatic control strategies Are defined for each individual ventilation plant, e.g. changes in temperature, volume flow, moisture content, readjustment between winter and summer periods. Differentiation is made between data of the physical components of the plant (in the company catalogue) and the control function (automatic or manual equipment). Default libraries tsbi3 comes with standard libraries for: constructions (walls, floors, roofs, and internal walls), materials, glass, window frames, people loads, schedules and national constants. The user can choose from these libraries or define new input.

	Input interface: Input is given as texts in a menu-driven DOS based environment.
Output	The user can define any of the calculated parameters (more than 67 for each zone plus data from ambient climate, central ventilation plant (if any) and solar walls (if any) as output on hourly basis, in either. tabular or graphically form. The variables can also be presented in "sum" graphs or tables. Finally the energy balances for each zone or the whole building can be shown.
Computer Platform	PC-compatible, 486 or higher.
Programming Language	C and assembler.
Advantages	Analysis of the indoor thermal climate in complex buildings or buildings with special requirements for the indoor climate.
Disadvantages	No true geometry, and thereby weak models for airflow's. Should not be used for detailed analyses of moisture conditions in indoor air.
Availability	Commercially Available

Program Name	VisualDOE
Brief Description	Windows interface to the DOE-2.1E energy simulation program. Through the graphical interface, users construct a model of the building's geometry using standard block shapes or using a built-in drawing tool. Building systems are defined through a point-and-click interface. A library of constructions, systems and operating schedules is included, and the user can add custom elements as well. If desired, the program assigns default values for parameters based on the vintage and size of the building. VisualDOE is especially useful for studies of envelope and HVAC design alternatives. Up to 20 alternatives can be defined for a single project. Summary reports and graphs may be printed directly from the program. Hourly reports of building parameters may also be viewed.
Expertise Required	Basic experience with Windows programs is important. Familiarity with building systems is desirable but not absolutely necessary. One to two days of training is also desirable but not necessary for those familiar with building modelling.
Users	300+, US and international.
Used By	Building designers (new and retrofit), researchers, equipment and utility marketers.
Input Requirements	Assigns default values to many of the inputs based on the building vintage and size. Required inputs include floor plan, occupancy

	type, and location. These are all that is required to run a simulation. Typically, however, inputs include wall, roof and floor constructions; window area and type; HVAC system type and parameters; and lighting and office equipment power.
Output	Produces input and output summary reports that may be viewed on-screen or printed. A number of graphs may be viewed and printed. These graphs can compare selected alternatives and/or selected hourly variables. Standard DOE-2.1E reports may be selected.
Computer Platform	Windows 3.1, Windows 95, or Windows NT. 486 or better, 8MB+ RAM, 30MB hard drive space.
Programming Language	Visual Basic and Visual C++
Advantages	Allows rapid development of energy simulations, dramatically reducing the time required to build a DOE-2 model. Specifying the building geometry is much faster than other comparable software, making VisualDOE useful for schematic design studies of the building envelope or HVAC systems. Uses DOE-2 as the simulation engine--an industry standard that has been shown to be accurate; implements DOE-2's daylighting calculations; allows input in SI or IP units; imports CADD data to define thermal zones. For advanced users, allows editing of equipment performance curves. Displays a 3D image of the model to help verify accuracy. Allows simple management of up to 20 design alternatives. Experienced DOE-2 users can use VisualDOE to create input files, modify them, and run them from within the program.
Disadvantages	Passive solar models may not be too accurate. Natural ventilation

	modelling is limited to a specified air changes per hour (ACH) that may be scheduled on or off. Underground buildings must be modelled with exterior walls, although custom constructions can be entered to represent the mass of the earth. Underfloor air distribution systems may provide benefits that are not directly modelled in DOE-2. For instance, DOE-2 does not account for thermal stratification in a space. Version 2.5 of VisualDOE does not support modelling of skylights.
Availability	Commercially Available

APPENDIX B

Building Services Engineers Questionnaire

BUILDING SERVICES ENGINEER QUESTIONEER

NAME

AGE

QUALIFICATIONS

NO. OF YEARS AS A DESIGN ENGINEER

COMPUTER ABILITY

Poor
Fair
Average
Good
Excellent

What method or programme do you currently use for calculating and assessing heating and cooling loads?

Why do you use this method or programme?

Do you consider this method or programme to be the most accurate, efficient and the best available?

What are the limitations of using this method or programme?

Are you comfortable with using this method and why?

Are you aware of any alternative methods or programmes of calculating and assessing heating and cooling loads?

What would convenience you to use alternative methods or programmes?

Have you ever designed using thermal simulation programmes?

Would you consider using a thermal simulation programme?

What advantages do you see thermal simulation has over the CIBSE steady state method or visa versa?

Are your answers based upon personal experience, from what you have heard or something else, explain your answer?

What projects would you foresee simulation being useful, if any?

Would a programme that showed the comparisons between a steady state calculation and a simulation calculation help to influence your decision?

Do you think it is worth time and money learning to use simulation programmes?

Do you think Building Services Engineers should have more of an influence at early stage of a project, in terms of the buildings layout, orientation, facade design, construction etc?

What is the most important in your view in an overall project?

Occupancy Comfort ______________________
Environmental Performance ______________________
Running Costs ______________________
Capital Cost ______________________
Getting the job done and out of the office ______________________
No worries, i.e. easy sleep ______________________

Do you care about the environment?

____

____

Can Building Services Engineers greatly influence in a positive manner the global, local and internal environmental?

____

____

BUILDING SERVICES ENGINEER QUESTIONEER

NAME — IAN MOLLOY

AGE — 22

QUALIFICATIONS — BUILDING SERVICES ENG TECH DIP + DEGREE (SOON)

NO. OF YEARS AS A DESIGN ENGINEER — 2

COMPUTER ABILITY

Poor

Fair

Average

Good ✓

Excellent

What method or programme do you currently use for calculating and assessing heating and cooling loads?

ESP, MACROFLO & SUNCAST.

Why do you use this method or programme?

BECAUSE IT IS THE MOST COMPREHENSIVE ENERGY SIMULATION TOOL AVAILABLE.

Do you consider this method or programme to be the most accurate, efficient and the best available?

YES, ALTHOUGH THERE ARE SOME OTHER GOOD PROGRAMS WHICH ARE NOT AS DEMANDING I.E. FACET - APACHE, BUT GIVE GOOD INFORMATION.

What are the limitations of using this method or programme?

Takes A Good Bit Of Skill & Can Be Quite Time Consuming.

Are you comfortable with using this method and why?

Yes, Because I Am Used To It And Have A Good Bit Of Experience Applying It To A Wide Variety Of Applications.

Are you aware of an alternative methods or programmes of calculating and assessing heating and cooling loads?

Yes, I Reckon I Would Know Them All, Although Most I Wouldn't Touch – TAS, Cymap, Hevacomp.

What would convenience you to use alternative methods or programmes?

If They Provided The Information I Need Then I Will Use Them, Oh Yes, And An Increase In Feed.

Have you ever designed using thermal simulation programmes?

Once Or Twice, I Wouldn't Trust That Stuff As Far As I Could Throw It ... Not.

Would you consider using a thermal simulation programme?

Only If I Was A Dumbass Building Services Engineer Without A Clue, If I Was On The Ball, Then I Wouldn't Have To Consider, I Would Already Be Doing It.

What advantages do you see thermal simulation has over the CIBSE method or visa versa?

IT PROVIDES THE TYPE, QUALITY & QUANTITY OF INFORMATION I NEED TO IDENTIFY & SOLVE PROBLEMS. CIBSE CANNOT DO THIS.

Are you answers based upon personal experience, from what you have heard or something else, explain your answer?

PERSONAL EXPERIENCE AND FROM WORKING WITH A TEAM OF EXPERTS IN THIS ~~FIELD~~ FIELD.

ALSO FROM THE FEEDBACK I GET FROM CLIENTS WHO HAVE BENEFITED FROM SIM.

What projects would you foresee simulation being useful, if any?

IT IS USEFUL ON ALL PROJECTS, BIG OR SMALL, SIMPLE OR COMPLEX.

Would a programme that showed the comparisons between a steady state calculation and a simulation calculation help to influence your decision?

YES IT WOULD SHOW ME THAT I'M RIGHT, BUT THEY ARE TWO DIFFERENT THINGS & IT IS DIFFICULT TO COMPARE.

Do you think it is worth time and money learning to use simulation programmes?

NOT A DOUBT IN THE WORLD, BUT IT IS SUITABLE FOR SOME NOT ALL ENGINEERS.

Do you think Building Services Engineers should have more of an influence at early stage of a project, in terms of the buildings layout, orientation, facade design, construction etc?

YES, IT IS AT THIS TIME THAT DECISIONS HAVING GREAT INFLUENCE ~~ON~~ THE ENERGY & ENVIRONMENTAL CONDITIONS IN THE SPACE ARE MADE.

What is the most important in your view in an overall project?

Occupancy Comfort	2
Environmental Performance	1
Running Costs	3
Capital Cost	4
Getting the job done and out of the office	5
No worries, i.e. easy sleep	I LIKE THIS ONE →

IF YOU USE SIM. THEN YOU CAN SLEEP EASILY.

Do you care about the environment?

YES.

Can Building Services Engineers greatly influence in a positive manner the global, local and internal environmental?

I WOULD SAY YES ON THE PRETEXT THAT THEY DESIGN THE WAY THEY REALLY SHOULD, IF THEY DON'T THEN THEY HAVE A NEGATIVE INFLUENCE.

BUILDING SERVICES ENGINEER QUESTIONEER

NAME NOEL COYLE

AGE 46

QUALIFICATIONS C+G. TECHNICIANS CERTIFICATE (HEATING, VENTILATION AND AIR CONDITIONING)

NO. OF YEARS AS A DESIGN ENGINEER 17 YEARS

COMPUTER ABILITY

Poor POOR
Fair
Average
Good
Excellent

What method or programme do you currently use for calculating and assessing heating and cooling loads?

CIBSE. / HEVACOMP

Why do you use this method or programme?

COMPULSORY

Do you consider this method or programme to be the most accurate, efficient and the best available?

YES

What are the limitations of using this method or programme?

PROVING IN PRACTICE

Are you comfortable with using this method and why?

YES — TRADITIONAL USE AND NO EXPERIENCE WITH ALTERNATIVE

Are you aware of any alternative methods or programmes of calculating and assessing heating and cooling loads?

YES — ASHRAE. / CARRIER

What would convenience you to use alternative methods or programmes?

DEMONSTRATION

Have you ever designed using thermal simulation programmes?

NO

Would you consider using a thermal simulation programme?

YES

What advantages do you see thermal simulation has over the CIBSE steady state method or visa versa?

NONE – WOULD SEE THERMAL SIMULATION AS COMPLIMENTARY TO CIBSE.

Are your answers based upon personal experience, from what you have heard or something else, explain your answer?

FROM WHAT I HAVE HEARD

What projects would you foresee simulation being useful, if any?

HIGH SPACES AND HEAVILY GLAZED AREAS

Would a programme that showed the comparisons between a steady state calculation and a simulation calculation help to influence your decision?

YES

Do you think it is worth time and money learning to use simulation programmes?

YES

Do you think Building Services Engineers should have more of an influence at early stage of a project, in terms of the buildings layout, orientation, facade design, construction etc?

YES

What is the most important in your view in an overall project?

Occupancy Comfort	
Environmental Performance	ENVIRONMENTAL PERFORMANCE
Running Costs	
Capital Cost	
Getting the job done and out of the office	
No worries, i.e. easy sleep	

Do you care about the environment?

YES

Can Building Services Engineers greatly influence in a positive manner the global, local and internal environmental?

YES

BUILDING SERVICES ENGINEER QUESTIONEER

NAME GARETH BAKER

AGE 28

QUALIFICATIONS TECH.ENG., DIP.ENG., BSc.Eng

NO. OF YEARS AS A DESIGN ENGINEER 4

COMPUTER ABILITY

- Poor
- Fair
- Average
- Good ✓
- Excellent

What method or programme do you currently use for calculating and assessing heating and cooling loads?

HEVACOMP, EXCEL (OWN DESIGN)

Why do you use this method or programme?

it is what is available

Do you consider this method or programme to be the most accurate, efficient and the best available?

NO

What are the limitations of using this method or programme?

Programme is based on Steady-state equations & assumptions

Are you comfortable with using this method and why?

In most practical applications it is adequate once used in conjunction with engineering experience

Are you aware of any alternative methods or programmes of calculating and assessing heating and cooling loads?

Yes

What would convenience you to use alternative methods or programmes?

if they were user friendly and quick

Have you ever designed using thermal simulation programmes?

No

Would you consider using a thermal simulation programme?

YES

What advantages do you see thermal simulation has over the CIBSE steady state method or visa versa?

Accuracy - Calculations that can not be done by steady - state

Are your answers based upon personal experience, from what you have heard or something else, explain your answer?

on what has been shown to me in demonstrations

What projects would you foresee simulation being useful, if any?

Large projects - Building studys

Would a programme that showed the comparisons between a steady state calculation and a simulation calculation help to influence your decision?

Not Necessary

Do you think it is worth time and money learning to use simulation programmes?

NOT AT Present

Do you think Building Services Engineers should have more of an influence at early stage of a project, in terms of the buildings layout, orientation, facade design, construction etc?

Yes

What is the most important in your view in an overall project?

Occupancy Comfort
Environmental Performance
Running Costs
Capital Cost
Getting the job done and out of the office
No worries, i.e. easy sleep

This depends on the project and on the client in question

Do you care about the environment?

Yes

Can decisions that Building Services Engineers make day - in day - out on a whole help improve the environment ?

I dont think it has a major influance

Can Building Services Engineers greatly influence in a positive manner the global, local and internal environmental and How?

No

BUILDING SERVICES ENGINEER QUESTIONEER

NAME: RICHARD MORAN.

AGE: 34.

QUALIFICATIONS: BEng. CEng. MIEI, MCIBSE.

NO. OF YEARS AS A DESIGN ENGINEER: 11.

COMPUTER ABILITY

Poor
Fair
Average: AVERAGE
Good
Excellent

What method or programme do you currently use for calculating and assessing heating and cooling loads?

HEVAC

Why do you use this method or programme?

FORMILAR WITH IT, ITS AVAILIBITY.

Do you consider this method or programme to be the most accurate, efficient and the best available?

Accuracy is Good But not 100%,
Efficiency is fairly Good.
Not in a position to comment on comparison with other programmes.

What are the limitations of using this method or programme?

You need a feel for pipe sizes based on Manual Calcs to Know when programme is off. Not always enough space for fitting Codes. Space Load Calcs. are OK.

Are you comfortable with using this method and why?

Yes, because it accuracy is good enough for the Building Services Industry! It producess consistant Results.

Are you aware of any alternative methods or programmes of calculating and assessing heating and cooling loads?

Manual Systems only.

What would convenience you to use alternative methods or programmes?

A bit of Research by myself. Using it on a trial Basis so that I could become confident in its accuracy and consistency.

Have you ever designed using thermal simulation programmes?

No.

Would you consider using a thermal simulation programme?

Yes.

What advantages do you see thermal simulation has over the CIBSE steady state method or visa versa?

From Basic Knowledge of thermal simulation I consider it to be more accurate and gives a more global picture.

Are your answers based upon personal experience, from what you have heard or something else, explain your answer?

Listening to Colleagues, CIBSE Articles.

What projects would you foresee simulation being useful, if any?

Large open spaces with High ceilings.
Naturally Ventilated Buildings.

Would a programme that showed the comparisons between a steady state calculation and a simulation calculation help to influence your decision?

Yes.

Do you think it is worth time and money learning to use simulation programmes?

Yes.

Do you think Building Services Engineers should have more of an influence at early stage of a project, in terms of the buildings layout, orientation, facade design, construction etc?

Yes.

What is the most important in your view in an overall project?

Occupancy Comfort	1.
Environmental Performance	} These need to be considered
Running Costs	2.
Capital Cost	} together. A compromise is nearly always required
Getting the job done and out of the office	4.
No worries, i.e. easy sleep	3

Do you care about the environment?

Yes.

Can Building Services Engineers greatly influence in a positive manner the global, local and internal environmental?

Can influence but not Greatly

APPENDIX C

Early Design Stage Program ~ Construction Data & Fabric Analysis

APPENDIX C ~ CONSTRUCTION DATA & FABRIC ANALYSIS

Element	**External Wall**
Construction Type	Lightweight Concrete Block, Polyinsulation & Plasterboard.

Description	**Thickness (mm)**	**Resistance (m^2K/W)**	**Conductivity (W/K m)**	**Capacitance (J/Kg K)**	**Density (kg/m^3)**
Concrete Block (Lightweight)	200	1.053	0.190	1000.0	600.0
Polyurethane Board	25	1.000	0.025	1400.0	30.0
Gypsum	10	0.063	0.160	840.0	950.0

Solar Absorptivity	0.70	
Outside Emmisivity	0.90	
Inside Emmisivity	0.90	
Outside Surface Resistance	0.060	m^2K/W
Inside Surface Resistance	0.117	m^2K/W
Outside Convective Heat Transfer Coefficient	11.540	W/m^2K
Inside Convective Heat Transfer Coefficient	3.000	W/m^2K
Outside Radiative Heat Transfer Coefficient	5.130	W/m^2K
Inside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Thermal Transmittance (U-Value)	0.436	W/m^2K
Admittance	0.960	W/m^2K
Decrement Factor	0.33	
Decrement Factor Time Lag	8	Hours
Surface Factor	0.92	

Element	Internal Wall
Construction Type	13mm Plaster (Lightweight), 105mm Brickwork (Inner Leaf) & 13mm Plaster (Lightweight)

Description	Thickness (mm)	Resistance (m^2K/W)	Conductivity (W/K m)	Capacitance (J/Kg K)	Density (kg/m^3)
Plaster (Lightweight)	13	0.081	0.160	1000.0	600.0
Brickwork (Inner Leaf)	105	0.169	0.620	800.0	1700.0
Plaster (Lightweight)	13	0.081	0.160	1000.0	600.0

Solar Absorptivity	0.70	
Outside Emmisivity	0.90	
Inside Emmisivity	0.90	
Outside Surface Resistance	0.117	m^2K/W
Inside Surface Resistance	0.117	m^2K/W
Outside Convective Heat Transfer Coefficient	3.000	W/m^2K
Inside Convective Heat Transfer Coefficient	3.000	W/m^2K
Outside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Inside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Thermal Transmittance (U-Value)	1.767	W/m^2K
Admittance	3.424	W/m^2K
Decrement Factor	0.62	
Decrement Factor Time Lag	5	Hours
Surface Factor	0.65	

Element	**Glazing**
Construction Type	6mm Pilkington Single Glazing

Description	**Reflectance**	**Resistance (m^2K/W)**	**Absorptance**	**Transmittance**	**Refractive Index**
Clear Float 6mm	0.070	0.000	0.150	0.780	1.526

Frame Occupies	20% of total area	
Outside Emmisivity	0.90	
Inside Emmisivity	0.90	
Outside Surface Resistance	0.060	m^2K/W
Inside Surface Resistance	0.117	m^2K/W
Outside Convective Heat Transfer Coefficient	11.540	W/m^2K
Inside Convective Heat Transfer Coefficient	3.000	W/m^2K
Outside Radiative Heat Transfer Coefficient	5.130	W/m^2K
Inside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Thermal Transmittance (U-Value)	5.30	W/m^2K

Element	Roof
Construction Type	Standard Floor Construction (Insulated to 1995 Regulations)

Description	Thickness (mm)	Resistance (m^2K/W)	Conductivity (W/K m)	Capacitance (J/Kg K)	Density (kg/m^3)
London Clay	75	0.532	1.410	1000.0	1900.0
Brickwork (Outer Leaf)	25	0.298	0.840	800.0	1700.0
Cast Concrete	100	0.088	1.130	1000.0	2000.0
Dense EPS Slab Insulation	25	1.000	0.025	1400.0	30.0
Chipboard	25	0.167	0.150	2093.0	800.0
Synthetic Carpet	10	0.167	0.060	2500.0	160.0

Solar Absorptivity	0.70	
Outside Emmisivity	0.90	
Inside Emmisivity	0.90	
Outside Surface Resistance	0.010	m^2K/W
Inside Surface Resistance	0.117	m^2K/W
Outside Convective Heat Transfer Coefficient	100.000	W/m^2K
Inside Convective Heat Transfer Coefficient	3.000	W/m^2K
Outside Radiative Heat Transfer Coefficient	5.130	W/m^2K
Inside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Thermal Transmittance (U-Value)	0.421	W/m^2K
Admittance	2.029	W/m^2K
Decrement Factor	0.00	
Decrement Factor Time Lag	10	Hours
Surface Factor	0.82	

Element	**Door**
Construction Type	Wooden Door

Description	**Thickness (mm)**	**Resistance (m^2K/W)**	**Conductivity (W/K m)**	**Capacitance (J/Kg K)**	**Density (kg/m^3)**
Pine (20% Moist)	35	0.250	0.140	2720.0	419.0

Solar Absorptivity	0.70	
Outside Emmisivity	0.90	
Inside Emmisivity	0.90	
Outside Surface Resistance	0.117	m^2K/W
Inside Surface Resistance	0.117	m^2K/W
Outside Convective Heat Transfer Coefficient	3.000	W/m^2K
Inside Convective Heat Transfer Coefficient	3.000	W/m^2K
Outside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Inside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Thermal Transmittance (U-Value)	2.065	W/m^2K
Admittance	2.350	W/m^2K
Decrement Factor	0.97	
Decrement Factor Time Lag	1	Hours
Surface Factor	0.74	

Element	Roof Glazing
Construction Type	Polycarbonate Double Glazed Roof Lights

Description	Reflectance	Resistance (m^2K/W)	Absorptance	Transmittance	Refractive Index
Thermoclear 8mm Polycarbonate Sheeting	0.050	0.000	0.080	0.150	1.590
Air Gap		0.100			
Thermoclear 8mm Polycarbonate Sheeting	0.050	0.000	0.080	0.150	1.590

Frame Occupies	30% of total area	
Outside Emmisivity	0.90	
Inside Emmisivity	0.90	
Outside Surface Resistance	0.040	m^2K/W
Inside Surface Resistance	0.117	m^2K/W
Outside Convective Heat Transfer Coefficient	19.870	W/m^2K
Inside Convective Heat Transfer Coefficient	3.000	W/m^2K
Outside Radiative Heat Transfer Coefficient	5.130	W/m^2K
Inside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Thermal Transmittance (U-Value)	3.89	W/m^2K

Element	**Internal Glazing**
Construction Type	6 mm Clear Float Glazing

Description	**Reflectance**	**Resistance (m^2K/W)**	**Absorptance**	**Transmittance**	**Refractive Index**
Clear Float 6mm	0.070	0.000	0.150	0.780	1.526

Frame Occupies	0.0% of total area	
Outside Emmisivity	0.90	
Inside Emmisivity	0.90	
Outside Surface Resistance	0.100	m^2K/W
Inside Surface Resistance	0.100	m^2K/W
Outside Convective Heat Transfer Coefficient	4.460	W/m^2K
Inside Convective Heat Transfer Coefficient	4.460	W/m^2K
Outside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Inside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Thermal Transmittance (U-Value)	5.00	W/m^2K

Element	Ceiling
Construction Type	100mm Reinforced-Concrete Ceiling

Description	Thickness (mm)	Resistance (m^2K/W)	Conductivity (W/K m)	Capacitance (J/Kg K)	Density (kg/m^3)
Cast Concrete (Dense)	100	0.071	1.400	840.0	2100.0

Solar Absorptivity	0.70	
Outside Emmisivity	0.90	
Inside Emmisivity	0.90	
Outside Surface Resistance	0.117	m^2K/W
Inside Surface Resistance	0.117	m^2K/W
Outside Convective Heat Transfer Coefficient	3.000	W/m^2K
Inside Convective Heat Transfer Coefficient	3.000	W/m^2K
Outside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Inside Radiative Heat Transfer Coefficient	5.540	W/m^2K
Thermal Transmittance (U-Value)	3.272	W/m^2K
Admittance	5.231	W/m^2K
Decrement Factor	0.77	
Decrement Factor Time Lag	3	Hours
Surface Factor	0.49	

APPENDIX D

Early Design Stage Program ~ Weather Details

APPENDIX D

Weather Details

Location:	Dublin (Airport)
Latitude:	53.43 N
Height above Sea Level	68.0 m
Haze Factor	0.9
Ground Reflectance	0.2

Month	Min. Dry Bulb Temperature	Max. Dry Bulb Temperature	Dry Bulb Temperature Lag	Min. Wet Bulb Temperature	Max. Wet Bulb Temperature	Wet Bulb Temperature Lag	Precipitation
January	0.40	13.00	1.00	-0.40	11.00	4.00	0.01
February	-1.20	13.20	4.00	-1.60	11.00	4.00	0.01
March	-1.40	15.00	1.00	-1.70	11.50	1.00	0.01
April	-2.10	15.30	3.00	-2.90	13.40	9.00	0.01
May	2.10	21.20	1.00	1.30	17.30	1.00	0.02
June	2.90	24.10	2.00	2.30	19.10	1.00	0.02
July	9.00	26.70	2.00	8.60	20.60	0.00	0.02
August	6.00	23.00	5.00	4.90	19.10	1.00	0.02
September	6.00	20.30	2.00	5.10	17.40	2.00	0.02
October	6.50	18.30	2.00	5.60	15.40	2.00	0.02
November	0.20	13.30	2.00	-0.20	12.00	2.00	0.01
December	-1.10	13.70	-2.00	-1.40	11.20	-1.00	0.01

APPENDIX E

Early Design Stage Program ~ Cost Plan Scenario Information

COST PLAN DATA FOR BASE BUILDING

Total Floor Area = 2200

			Weight	Code	Rate	Cost	Percent of Total
1		**SUBSTRUCTURE**					
	1A	Substructure	1	11	IR£48.21	IR£106,062.00	4.8
						IR£106,062.00	4.8
2		**SUPERSTRUCTURE**					
	2A	Frame	1	11	IR£40.52	IR£89,144.00	4.0
	2B	Upper Floors	1	11	IR£42.41	IR£93,302.00	4.2
	2C	Roof	1	11	IR£91.42	IR£201,124.00	9.1
	2D	Stairs	1	11	IR£16.80	IR£36,960.00	1.7
	2E	External Walls	1	11	IR£101.90	IR£224,180.00	10.1
	2F	Windows & External Doors	1	11	IR£28.29	IR£62,238.00	2.8
	2G	Internal Walls & Partitions	1	11	IR£53.40	IR£117,480.00	5.3
	2H	Internal Doors	1	11	IR£28.10	IR£61,820.00	2.8
						IR£886,248.00	39.9
3		**INTERNAL FINISHES**					
	3A	Wall Finishes	1	11	IR£31.64	IR£69,608.00	3.1
	3B	Floor Finishes	1	11	IR£36.96	IR£81,312.00	3.7
	3C	Ceiling Finishes	1	11	IR£21.02	IR£46,244.00	2.1
	3D	Decorations	1	1	IR£0.00	IR£0.00	0.0
						IR£197,164.00	8.9
4		**FITTINGS & FURNISHINGS**					
	4A	Fittings & Fiunishings	1	11	IR£28.64	IR£63,008.00	2.8
						IR£63,008.00	2.8
5		**SERVICES**					
	5A	Sanitary Applicances	1	11	IR£9.48	IR£20,856.00	0.9
	5B	Services Equipment	1	11	IR£1.74	IR£3,828.00	0.2
	5C	Disposal Installation	1	11	IR£4.94	IR£10,868.00	0.5
	5D	Water Installation	1	11	IR£7.62	IR£16,764.00	0.8
	5E	Heating	1	11	IR£128.48	IR£282,656.00	12.7
	5F	Ventilation	1	1	IR£0.00	IR£0.00	0.0
	5G	Air Conditioning	1	1	IR£0.00	IR£0.00	0.0
	5H	Electrical Installations	1	11	IR£103.97	IR£228,734.00	10.3
	5I	Gas Installations	1	1	IR£0.00	IR£0.00	0.0
	5J	Lifts & Conveyors	1	11	IR£13.07	IR£28,754.00	1.3
	5K	Protective Installations	1	11	IR£13.16	IR£28,952.00	1.3
	5L	Communications	1	11	IR£18.47	IR£40,634.00	1.8
	5M	Special Installations	1	1	IR£0.00	IR£0.00	0.0
	5N	B.W.I.C	1	11	IR£14.68	IR£32,296.00	1.5
	5O	Profit & Attendance	1	1	IR£0.00	IR£0.00	0.0
						IR£694,342.00	31.3
6		**EXTERNAL WORKS**					
	6A	Site Works	1	1	IR£0.00	IR£0.00	0.0
	6B	Drainage	1	1	IR£0.00	IR£0.00	0.0
	6C	External Services	1	11	IR£123.94	IR£272,668.00	12.3
	6D	Minor Building Works	1	1	IR£0.00	IR£0.00	0.0
						IR£272,668.00	12.3
					Total	IR£2,219,492.00	100.0

SUMMARY OF CATEGORIES

Area = 2200

		Percent	Category Costs	Pounds / sq. m
1	SUBSTRUCTURE	4.78	IR£106,062.00	IR£48.21
2	SUPERSTRUCTURE	39.93	IR£886,248.00	IR£402.84
3	INTERNAL FINISHES	8.88	IR£197,164.00	IR£89.62
4	FITTINGS & FURNISHINGS	2.84	IR£63,008.00	IR£28.64
5	SERVICES	31.28	IR£694,342.00	IR£315.61
6	EXTERNAL WORKS	12.29	IR£272,668.00	IR£123.94
			IR£2,219,492.00	IR£1,008.86

Scenario 1

COST PLAN DATA FOR BASE BUILDING

Total Floor Area = 2200

			Weight	Code	Rate	Cost	Percent of Total
1		**SUBSTRUCTURE**					
	1A	Substructure	1	11	IR£48.21	IR£106,062.00	4.8
						IR£106,062.00	4.8
2		**SUPERSTRUCTURE**					
	2A	Frame	1	11	IR£40.52	IR£89,144.00	4.0
	2B	Upper Floors	1	11	IR£42.41	IR£93,302.00	4.2
	2C	Roof	1	11	IR£91.42	IR£201,124.00	9.1
	2D	Stairs	1	11	IR£16.80	IR£36,960.00	1.7
	2E	External Walls	1	11	IR£101.90	IR£224,180.00	10.1
	2F	Windows & External Doors	1	11	IR£28.29	IR£62,238.00	2.8
	2G	Internal Walls & Partitions	1	11	IR£53.40	IR£117,480.00	5.3
	2H	Internal Doors	1	11	IR£28.10	IR£61,820.00	2.8
						IR£886,248.00	39.9
3		**INTERNAL FINISHES**					
	3A	Wall Finishes	1	11	IR£31.64	IR£69,608.00	3.1
	3B	Floor Finishes	1	11	IR£36.96	IR£81,312.00	3.7
	3C	Ceiling Finishes	1	11	IR£21.02	IR£46,244.00	2.1
	3D	Decorations	1	1	IR£0.00	IR£0.00	0.0
						IR£197,164.00	8.9
4		**FITTINGS & FURNISHINGS**					
	4A	Fittings & Fiunishings	1	11	IR£28.64	IR£63,008.00	2.8
						IR£63,008.00	2.8
5		**SERVICES**					
	5A	Sanitary Applicances	1	11	IR£9.48	IR£20,856.00	0.9
	5B	Services Equipment	1	11	IR£1.74	IR£3,828.00	0.2
	5C	Disposal Installation	1	11	IR£4.94	IR£10,868.00	0.5
	5D	Water Installation	1	11	IR£7.62	IR£16,764.00	0.8
	5E	Heating	1	11	IR£128.48	IR£282,656.00	12.7
	5F	Ventilation	1	1	IR£0.00	IR£0.00	0.0
	5G	Air Conditioning	1	1	IR£0.00	IR£0.00	0.0
	5H	Electrical Installations	1	11	IR£103.97	IR£228,734.00	10.3
	5I	Gas Installations	1	1	IR£0.00	IR£0.00	0.0
	5J	Lifts & Conveyors	1	11	IR£13.07	IR£28,754.00	1.3
	5K	Protective Installations	1	11	IR£13.16	IR£28,952.00	1.3
	5L	Communications	1	11	IR£18.47	IR£40,634.00	1.8
	5M	Special Installations	1	1	IR£0.00	IR£0.00	0.0
	5N	B.W.I.C	1	11	IR£14.68	IR£32,296.00	1.5
	5O	Profit & Attendance	1	1	IR£0.00	IR£0.00	0.0
						IR£694,342.00	31.3
6		**EXTERNAL WORKS**					
	6A	Site Works	1	1	IR£0.00	IR£0.00	0.0
	6B	Drainage	1	1	IR£0.00	IR£0.00	0.0
	6C	External Services	1	11	IR£123.94	IR£272,668.00	12.3
	6D	Minor Building Works	1	1	IR£0.00	IR£0.00	0.0
						IR£272,668.00	12.3
					Total	IR£2,219,492.00	100.0

SUMMARY OF CATEGORIES

Area = **2200**

		Percent	Category Costs	Pounds / sq. m
1	SUBSTRUCTURE	4.78	IR£106,062.00	IR£48.21
2	SUPERSTRUCTURE	39.93	IR£886,248.00	IR£402.84
3	INTERNAL FINISHES	8.88	IR£197,164.00	IR£89.62
4	FITTINGS & FURNISHINGS	2.84	IR£63,008.00	IR£28.64
5	SERVICES	31.28	IR£694,342.00	IR£315.61
6	EXTERNAL WORKS	12.29	IR£272,668.00	IR£123.94
			IR£2,219,492.00	IR£1,008.86

Scenario 2

COST PLAN DATA FOR BASE BUILDING

Total Floor Area = 2200 3.5 m high floors

			Weight	Code	Rate	Cost	Percent of Total
1		SUBSTRUCTURE					
	1A	Substructure	1	11	IR£48.21	IR£106,062.00	5.0
						IR£106,062.00	5.0
2		SUPERSTRUCTURE					
	2A	Frame	1	11	IR£38.52	IR£84,744.00	4.0
	2B	Upper Floors	1	11	IR£42.41	IR£93,302.00	4.4
	2C	Roof	1	11	IR£91.42	IR£201,124.00	9.4
	2D	Stairs	1	11	IR£16.10	IR£35,420.00	1.7
	2E	External Walls	1	11	IR£81.90	IR£180,180.00	8.4
	2F	Windows & External Doors	1	11	IR£27.29	IR£60,038.00	2.8
	2G	Internal Walls & Partitions	1	11	IR£50.02	IR£110,044.00	5.2
	2H	Internal Doors	1	11	IR£26.50	IR£58,300.00	2.7
						IR£823,152.00	38.6
3		INTERNAL FINISHES					
	3A	Wall Finishes	1	11	IR£29.64	IR£65,208.00	3.1
	3B	Floor Finishes	1	11	IR£36.96	IR£81,312.00	3.8
	3C	Ceiling Finishes	1	11	IR£21.02	IR£46,244.00	2.2
	3D	Decorations	1	1	IR£0.00	IR£0.00	0.0
						IR£192,764.00	9.0
4		FITTINGS & FURNISHINGS					
	4A	Fittings & Fiunishings	1	11	IR£28.64	IR£63,008.00	3.0
						IR£63,008.00	3.0
5		SERVICES					
	5A	Sanitary Applicances	1	11	IR£9.48	IR£20,856.00	1.0
	5B	Services Equipment	1	11	IR£1.74	IR£3,828.00	0.2
	5C	Disposal Installation	1	11	IR£4.94	IR£10,868.00	0.5
	5D	Water Installation	1	11	IR£7.62	IR£16,764.00	0.8
	5E	Heating	1	11	IR£120.48	IR£265,056.00	12.4
	5F	Ventilation	1	1	IR£0.00	IR£0.00	0.0
	5G	Air Conditioning	1	1	IR£0.00	IR£0.00	0.0
	5H	Electrical Installations	1	11	IR£103.97	IR£228,734.00	10.7
	5I	Gas Installations	1	1	IR£0.00	IR£0.00	0.0
	5J	Lifts & Conveyors	1	11	IR£13.07	IR£28,754.00	1.3
	5K	Protective Installations	1	11	IR£13.16	IR£28,952.00	1.4
	5L	Communications	1	11	IR£18.47	IR£40,634.00	1.9
	5M	Special Installations	1	1	IR£0.00	IR£0.00	0.0
	5N	B.W.I.C	1	11	IR£14.68	IR£32,296.00	1.5
	5O	Profit & Attendance	1	1	IR£0.00	IR£0.00	0.0
						IR£676,742.00	31.7
6		EXTERNAL WORKS					
	6A	Site Works	1	1	IR£0.00	IR£0.00	0.0
	6B	Drainage	1	1	IR£0.00	IR£0.00	0.0
	6C	External Services	1	11	IR£123.94	IR£272,668.00	12.8
	6D	Minor Building Works	1	1	IR£0.00	IR£0.00	0.0
						IR£272,668.00	12.8
					Total	IR£2,134,396.00	100.0

SUMMARY OF CATEGORIES

Area = **2200**

		Percent	**Category Costs**	**Pounds / sq. m**
1	SUBSTRUCTURE	4.97	IR£106,062.00	IR£48.21
2	SUPERSTRUCTURE	38.57	IR£823,152.00	IR£374.16
3	INTERNAL FINISHES	9.03	IR£192,764.00	IR£87.62
4	FITTINGS & FURNISHINGS	2.95	IR£63,008.00	IR£28.64
5	SERVICES	31.71	IR£676,742.00	IR£307.61
6	EXTERNAL WORKS	12.77	IR£272,668.00	IR£123.94
			IR£2,134,396.00	IR£970.18

Scenario 3

COST PLAN DATA FOR BASE BUILDING

Total Floor Area = 2200 3.0 m high floors

			Weight	Code	Rate	Cost	Percent of Total
1		SUBSTRUCTURE					
	1A	Substructure	1	11	IR£48.21	IR£106,062.00	5.0
						IR£106,062.00	5.0
2		SUPERSTRUCTURE					
	2A	Frame	1	11	IR£36.52	IR£80,344.00	3.8
	2B	Upper Floors	1	11	IR£42.41	IR£93,302.00	4.4
	2C	Roof	1	11	IR£91.42	IR£201,124.00	9.6
	2D	Stairs	1	11	IR£15.50	IR£34,100.00	1.6
	2E	External Walls	1	11	IR£77.90	IR£171,380.00	8.2
	2F	Windows & External Doors	1	11	IR£27.29	IR£60,038.00	2.9
	2G	Internal Walls & Partitions	1	11	IR£48.02	IR£105,644.00	5.0
	2H	Internal Doors	1	11	IR£26.50	IR£58,300.00	2.8
						IR£804,232.00	38.3
3		INTERNAL FINISHES					
	3A	Wall Finishes	1	11	IR£28.64	IR£63,008.00	3.0
	3B	Floor Finishes	1	11	IR£36.96	IR£81,312.00	3.9
	3C	Ceiling Finishes	1	11	IR£21.02	IR£46,244.00	2.2
	3D	Decorations	1	1	IR£0.00	IR£0.00	0.0
						IR£190,564.00	9.1
4		FITTINGS & FURNISHINGS					
	4A	Fittings & Fiunishings	1	11	IR£28.64	IR£63,008.00	3.0
						IR£63,008.00	3.0
5		SERVICES					
	5A	Sanitary Applicances	1	11	IR£9.48	IR£20,856.00	1.0
	5B	Services Equipment	1	11	IR£1.74	IR£3,828.00	0.2
	5C	Disposal Installation	1	11	IR£4.94	IR£10,868.00	0.5
	5D	Water Installation	1	11	IR£7.62	IR£16,764.00	0.8
	5E	Heating	1	11	IR£115.48	IR£254,056.00	12.1
	5F	Ventilation	1	1	IR£0.00	IR£0.00	0.0
	5G	Air Conditioning	1	1	IR£0.00	IR£0.00	0.0
	5H	Electrical Installations	1	11	IR£103.97	IR£228,734.00	10.9
	5I	Gas Installations	1	1	IR£0.00	IR£0.00	0.0
	5J	Lifts & Conveyors	1	11	IR£13.07	IR£28,754.00	1.4
	5K	Protective Installations	1	11	IR£13.16	IR£28,952.00	1.4
	5L	Communications	1	11	IR£18.47	IR£40,634.00	1.9
	5M	Special Installations	1	1	IR£0.00	IR£0.00	0.0
	5N	B.W.I.C	1	11	IR£14.68	IR£32,296.00	1.5
	5O	Profit & Attendance	1	1	IR£0.00	IR£0.00	0.0
						IR£665,742.00	31.7
6		EXTERNAL WORKS					
	6A	Site Works	1	1	IR£0.00	IR£0.00	0.0
	6B	Drainage	1	1	IR£0.00	IR£0.00	0.0
	6C	External Services	1	11	IR£123.94	IR£272,668.00	13.0
	6D	Minor Building Works	1	1	IR£0.00	IR£0.00	0.0
						IR£272,668.00	13.0
					Total	IR£2,102,276.00	100.0

Scenario 4

COST PLAN DATA FOR BASE BUILDING

Total Floor Area = 3300   **3 Floors & 3.0 m High**

			Weight	Code	Rate	Cost	Percent of Total
1		**SUBSTRUCTURE**					
	1A	Substructure	1	11	IR£60.29	IR£198,957.00	6.5
						IR£198,957.00	6.5
2		**SUPERSTRUCTURE**					
	2A	Frame	1	11	IR£53.95	IR£178,035.00	5.8
	2B	Upper Floors	1	11	IR£32.28	IR£106,524.00	3.5
	2C	Roof	1	11	IR£64.70	IR£213,510.00	7.0
	2D	Stairs	1	11	IR£17.64	IR£58,212.00	1.9
	2E	External Walls	1	11	IR£85.83	IR£283,239.00	9.3
	2F	Windows & External Doors	1	11	IR£27.29	IR£90,057.00	2.9
	2G	Internal Walls & Partitions	1	11	IR£50.19	IR£165,627.00	5.4
	2H	Internal Doors	1	11	IR£29.17	IR£96,261.00	3.2
						IR£1,191,465.00	39.0
3		**INTERNAL FINISHES**					
	3A	Wall Finishes	1	11	IR£30.84	IR£101,772.00	3.3
	3B	Floor Finishes	1	11	IR£36.02	IR£118,866.00	3.9
	3C	Ceiling Finishes	1	11	IR£19.85	IR£65,505.00	2.1
	3D	Decorations	1	1	IR£0.00	IR£0.00	0.0
						IR£286,143.00	9.4
4		**FITTINGS & FURNISHINGS**					
	4A	Fittings & Fiunishings	1	11	IR£28.64	IR£94,512.00	3.1
						IR£94,512.00	3.1
5		**SERVICES**					
	5A	Sanitary Applicances	1	11	IR£9.87	IR£32,571.00	1.1
	5B	Services Equipment	1	11	IR£1.55	IR£5,115.00	0.2
	5C	Disposal Installation	1	11	IR£6.45	IR£21,285.00	0.7
	5D	Water Installation	1	11	IR£7.03	IR£23,199.00	0.8
	5E	Heating	1	11	IR£94.85	IR£313,005.00	10.3
	5F	Ventilation	1	1	IR£0.00	IR£0.00	0.0
	5G	Air Conditioning	1	1	IR£0.00	IR£0.00	0.0
	5H	Electrical Installations	1	11	IR£86.60	IR£285,780.00	9.4
	5I	Gas Installations	1	1	IR£0.00	IR£0.00	0.0
	5J	Lifts & Conveyors	1	11	IR£16.46	IR£54,318.00	1.8
	5K	Protective Installations	1	11	IR£9.74	IR£32,142.00	1.1
	5L	Communications	1	11	IR£15.89	IR£52,437.00	1.7
	5M	Special Installations	1	1	IR£0.00	IR£0.00	0.0
	5N	B.W.I.C	1	11	IR£16.89	IR£55,737.00	1.8
	5O	Profit & Attendance	1	1	IR£0.00	IR£0.00	0.0
						IR£875,589.00	28.7
6		**EXTERNAL WORKS**					
	6A	Site Works	1	1	IR£0.00	IR£0.00	0.0
	6B	Drainage	1	1	IR£0.00	IR£0.00	0.0
	6C	External Services	1	11	IR£123.32	IR£406,956.00	13.3
	6D	Minor Building Works	1	1	IR£0.00	IR£0.00	0.0
						IR£406,956.00	13.3
					Total	IR£3,053,622.00	100.0

SUMMARY OF CATEGORIES

Area = 3300

		Percent	Category Costs	Pounds / sq. m
1	SUBSTRUCTURE	6.5	IR£198,957.00	IR£60.29
2	SUPERSTRUCTURE	39.0	IR£1,191,465.00	IR£361.05
3	INTERNAL FINISHES	9.4	IR£286,143.00	IR£86.71
4	FITTINGS & FURNISHINGS	3.1	IR£94,512.00	IR£28.64
5	SERVICES	28.7	IR£875,589.00	IR£265.33
6	EXTERNAL WORKS	13.3	IR£406,956.00	IR£123.32
			IR£3,053,622.00	IR£925.34

Scenario 5

COST PLAN DATA FOR BASE BUILDING

Total Floor Area = 2200 3.0 m high floors

			Weight	Code	Rate	Cost	Percent of Total
1		**SUBSTRUCTURE**					
	1A	Substructure	1	11	IR£48.21	IR£106,062.00	5.0
						IR£106,062.00	5.0
2		**SUPERSTRUCTURE**					
	2A	Frame	1	11	IR£36.52	IR£80,344.00	3.8
	2B	Upper Floors	1	11	IR£42.41	IR£93,302.00	4.4
	2C	Roof	1	11	IR£91.42	IR£201,124.00	9.6
	2D	Stairs	1	11	IR£15.50	IR£34,100.00	1.6
	2E	External Walls	1	11	IR£77.90	IR£171,380.00	8.2
	2F	Windows & External Doors	1	11	IR£27.29	IR£60,038.00	2.9
	2G	Internal Walls & Partitions	1	11	IR£48.02	IR£105,644.00	5.0
	2H	Internal Doors	1	11	IR£26.50	IR£58,300.00	2.8
						IR£804,232.00	38.3
3		**INTERNAL FINISHES**					
	3A	Wall Finishes	1	11	IR£28.64	IR£63,008.00	3.0
	3B	Floor Finishes	1	11	IR£36.96	IR£81,312.00	3.9
	3C	Ceiling Finishes	1	11	IR£21.02	IR£46,244.00	2.2
	3D	Decorations	1	1	IR£0.00	IR£0.00	0.0
						IR£190,564.00	9.1
4		**FITTINGS & FURNISHINGS**					
	4A	Fittings & Fiunishings	1	11	IR£28.64	IR£63,008.00	3.0
						IR£63,008.00	3.0
5		**SERVICES**					
	5A	Sanitary Applicances	1	11	IR£9.48	IR£20,856.00	1.0
	5B	Services Equipment	1	11	IR£1.74	IR£3,828.00	0.2
	5C	Disposal Installation	1	11	IR£4.94	IR£10,868.00	0.5
	5D	Water Installation	1	11	IR£7.62	IR£16,764.00	0.8
	5E	Heating	1	11	IR£115.48	IR£254,056.00	12.1
	5F	Ventilation	1	1	IR£0.00	IR£0.00	0.0
	5G	Air Conditioning	1	1	IR£0.00	IR£0.00	0.0
	5H	Electrical Installations	1	11	IR£103.97	IR£228,734.00	10.9
	5I	Gas Installations	1	1	IR£0.00	IR£0.00	0.0
	5J	Lifts & Conveyors	1	11	IR£13.07	IR£28,754.00	1.4
	5K	Protective Installations	1	11	IR£13.16	IR£28,952.00	1.4
	5L	Communications	1	11	IR£18.47	IR£40,634.00	1.9
	5M	Special Installations	1	1	IR£0.00	IR£0.00	0.0
	5N	B.W.I.C	1	11	IR£14.68	IR£32,296.00	1.5
	5O	Profit & Attendance	1	1	IR£0.00	IR£0.00	0.0
						IR£665,742.00	31.7
6		**EXTERNAL WORKS**					
	6A	Site Works	1	1	IR£0.00	IR£0.00	0.0
	6B	Drainage	1	1	IR£0.00	IR£0.00	0.0
	6C	External Services	1	11	IR£123.94	IR£272,668.00	13.0
	6D	Minor Building Works	1	1	IR£0.00	IR£0.00	0.0
						IR£272,668.00	13.0
					Total	IR£2,102,276.00	100.0

SUMMARY OF CATEGORIES

Area = **2200**

		Percent	Category Costs	Pounds / sq. m
1	SUBSTRUCTURE	5.0	IR£106,062.00	IR£48.21
2	SUPERSTRUCTURE	38.3	IR£804,232.00	IR£365.56
3	INTERNAL FINISHES	9.1	IR£190,564.00	IR£86.62
4	FITTINGS & FURNISHINGS	3.0	IR£63,008.00	IR£28.64
5	SERVICES	31.7	IR£665,742.00	IR£302.61
6	EXTERNAL WORKS	13.0	IR£272,668.00	IR£123.94
			IR£2,102,276.00	IR£955.58

Scenario 6

COST PLAN DATA FOR BASE BUILDING

Total Floor Area = 1984

			Weight	Code	Rate	Cost	Percent of Total
1		**SUBSTRUCTURE**					
	1A	Substructure	1	11	IR£48.21	IR£95,648.64	4.7
						IR£95,648.64	4.7
2		**SUPERSTRUCTURE**					
	2A	Frame	1	11	IR£40.52	IR£80,391.68	4.0
	2B	Upper Floors	1	11	IR£41.41	IR£82,157.44	4.1
	2C	Roof	1	11	IR£88.42	IR£175,425.28	8.7
	2D	Stairs	1	11	IR£16.80	IR£33,331.20	1.6
	2E	External Walls	1	11	IR£121.90	IR£241,849.60	12.0
	2F	Windows & External Doors	1	11	IR£32.29	IR£64,063.36	3.2
	2G	Internal Walls & Partitions	1	11	IR£44.40	IR£88,089.60	4.4
	2H	Internal Doors	1	11	IR£28.10	IR£55,750.40	2.8
						IR£821,058.56	40.6
3		**INTERNAL FINISHES**					
	3A	Wall Finishes	1	11	IR£31.64	IR£62,773.76	3.1
	3B	Floor Finishes	1	11	IR£36.96	IR£73,328.64	3.6
	3C	Ceiling Finishes	1	11	IR£21.02	IR£41,703.68	2.1
	3D	Decorations	1	1	IR£0.00	IR£0.00	0.0
						IR£177,806.08	8.8
4		**FITTINGS & FURNISHINGS**					
	4A	Fittings & Fiunishings	1	11	IR£28.64	IR£56,821.76	2.8
						IR£56,821.76	2.8
5		**SERVICES**					
	5A	Sanitary Applicances	1	11	IR£9.48	IR£18,808.32	0.9
	5B	Services Equipment	1	11	IR£1.74	IR£3,452.16	0.2
	5C	Disposal Installation	1	11	IR£4.94	IR£9,800.96	0.5
	5D	Water Installation	1	11	IR£7.62	IR£15,118.08	0.7
	5E	Heating	1	11	IR£128.48	IR£254,904.32	12.6
	5F	Ventilation	1	1	IR£0.00	IR£0.00	0.0
	5G	Air Conditioning	1	1	IR£0.00	IR£0.00	0.0
	5H	Electrical Installations	1	11	IR£103.97	IR£206,276.48	10.2
	5I	Gas Installations	1	1	IR£0.00	IR£0.00	0.0
	5J	Lifts & Conveyors	1	11	IR£13.07	IR£25,930.88	1.3
	5K	Protective Installations	1	11	IR£13.16	IR£26,109.44	1.3
	5L	Communications	1	11	IR£18.47	IR£36,644.48	1.8
	5M	Special Installations	1	1	IR£0.00	IR£0.00	0.0
	5N	B.W.I.C	1	11	IR£14.68	IR£29,125.12	1.4
	5O	Profit & Attendance	1	1	IR£0.00	IR£0.00	0.0
						IR£626,170.24	30.9
6		**EXTERNAL WORKS**					
	6A	Site Works	1	1	IR£0.00	IR£0.00	0.0
	6B	Drainage	1	1	IR£0.00	IR£0.00	0.0
	6C	External Services	1	11	IR£123.94	IR£245,896.96	12.2
	6D	Minor Building Works	1	1	IR£0.00	IR£0.00	0.0
						IR£245,896.96	12.2
					Total	IR£2,023,402.24	100.0

SUMMARY OF CATEGORIES

Area = 2200

		Percent	Category Costs	Pounds / sq. m
1	SUBSTRUCTURE	4.7	IR£95,648.64	IR£43.48
2	SUPERSTRUCTURE	40.6	IR£821,058.56	IR£373.21
3	INTERNAL FINISHES	8.8	IR£177,806.08	IR£80.82
4	FITTINGS & FURNISHINGS	2.8	IR£56,821.76	IR£25.83
5	SERVICES	30.9	IR£626,170.24	IR£284.62
6	EXTERNAL WORKS	12.2	IR£245,896.96	IR£111.77
			IR£2,023,402.24	IR£919.73