Modelling Study of Energy Use on a Construction Site

by

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Copyright statement

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Abstract

The need for energy conservation is a real challenge, worthy of everyone's attention. Recently, the energy crisis has led to an increased discussion by the public of the pros and cons of different kinds of energy. This is because utility rates are continuing to climb; natural gas rates are increasing; and fuel oil prices are sharply rocketing.
On the same time, limited fuel resources are being depleted, and some countries are becoming increasingly dependent upon oil and gas importation. So, many companies are deeply concerned with this situation because their businesses are seriously affected.

The aim of this thesis is to perform a modelling study of energy use on a construction site, to meet the heat and lighting requirements within a temporary accommodation. The focus of this research was on temporary accommodation because it has received relatively little attention to date, and it was found that the energy usage within temporary cabin accommodation is not well controlled at present.

Through literature review, various energy efficient methods and technologies were studied, and different energy savings opportunities were identified. In the case study, different technologies options were modelled to determine their technical and economic performance; and a feasibility study of heating and lighting requirements within cabin accommodation was undertaken.

The analysis made use the ESP-r simulation program and considered the impact of the design changes options (such as insulation; glazing types; etc.) not only on the energy usage, but also in terms of other performance criteria particularly the thermal comfort. The results of this study allowed some general conclusions to be reached and confirmed the benefits associated with these technologies.

Finally, an analysis was carried out to determine the CO_2 emissions savings that could be achieved with good management and best practice.

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I. Introduction

The energy consumed on a construction site varies continuously, and generally increases as a project progress. The usual practice of considering annual energy consumption is wholly inappropriate for the construction businesses because every project is different, and projects run only for a short term period.

However, as the annual energy consumed within cabins on a construction site is relatively constant, it is possible to establish benchmarks for energy performance based on standards of cabins. This could be achieved by using a thermal simulation program. And the result would be used to compare similar cabins or using the current consumption figures against advanced cabins with higher levels of insulation and units which meet new building regulations.

The focus of this research was on total energy use within the National Air Traffic Service (NATS) cabins because it was found that the energy usage is not well controlled at present [17]; and temporary accommodation has received relatively little attention to date. Since some construction companies wish to become more sustainable, the results of this study would help them to achieve their goals.

Energy saving opportunities through innovative approach and new technologies were identified; and a specification for energy efficient prefabricated cabins was outlined.

This research focused mostly on the heating and lighting systems within cabin accommodation, and it is broken into two main parts within it are grouped different chapters. The organisation is presented as follow:

Part I:

This part covers two major chapters. The first concerns energy policy, and considers the organisation, structure and lines of communication. The second chapter concerns energy efficient technology in a temporary accommodation. This latter is divided into two main sub-chapters. The first provides detailed information on lighting systems. This includes natural lighting, artificial lighting, lighting controls, and lighting design and measurement. The second sub-chapter is about the heating systems in a temporary accommodation. It describes briefly space heating equipment, the heating controls in a temporary accommodation, and building design for rational energy use on heating systems.

Part II:

This part concerns a case study. It is broken into four chapters. The first one describes the company's background and one of its construction sites: National Air Traffic Service (NATS) centre, and contains details related to the NATS cabins description and structure. The second chapter describes the methodology followed to run a simulation program, and gives details on simulation strategies. The third chapter concerns the results analysis. It illustrates the results obtained from the simulations analysis performed on heating systems including details on the effects of some design changes such as increasing wall insulation, changing glazing types, changing the heating controls, and identifies impacts that building infiltration air flow can make to the total energy consumed within NATS cabins.

The fourth chapter addresses the economic aspects on heating and lighting systems.

And finally, this thesis ends with conclusions and recommendations for future work.

PART I: Energy use on a construction site

II. Energy policy

II.1. Introduction

Within many organisations, there is a general understanding of responsibilities and accountability for energy consumed, but very few amongst them have a formal energy policy. [15]

Energy policy is the framework from which the operating principles of energy management are derived. It is what needed to know in order to establish the doctrine for prudent management of the business.

Policy gives operations the discipline which permits managers to optimize decisions in order to maximize their profits. And its establishment is the responsibility of the top management. Responsibilities and accountability for energy consumption may be clearly written down by a committee or someone on the staff. And it is also necessary to distribute it routinely to all relevant employees.

Without a written energy policy, the commitment to saving energy is left to operate on an unofficial basis, and then decisions are made randomly and generally by intuition. Thus, where commitment is absent or informal, there is a lack of decision making at different levels, and this can undermine the energy management process. [15]

II.2. Aims and objectives

Energy management on a construction site aims to control energy consumption in order to avoid unnecessary expenditure, and save money. It improves cost-effectiveness and working conditions, protect the environment and prolong the useful life of equipments and fuels.

The long term objectives are to buy fuels at the most economic costs; to burn and use them as efficient as is practicable; to reduce the amount of pollution, particularly carbon dioxide emissions caused by energy consumption.

In the short term, energy management aims are:

- to gain control over energy consumption by reviewing and improving the purchasing; the operating and training practices.
- to invest in an energy saving programme, which will maximize returns on investment
- to safeguard the gains by establishing and maintaining the management information system designed to ensure that information is delivered to those who need it, on time and in a form which supports their managerial decision making.

II.3. Energy policy in perspective

Escalating energy costs are putting pressure on management budgets. So, a thorough energy management is a means to a particular end – safeguarding an industrial business, so that it can pursue its activities without hindering by disruptions to its energy supply or by having to bear unnecessary costs. It is imperative that management using all available resources be prepared to face problems of energy shortages and rising costs.

Saving energy should not be pursued without due attention to its effects on other aspects of the industry’s operations, e.g. staff morale, fuel consumption and building related health risks. Other issues such as the depletion of finite resources; pollution and the environment degradation also need careful attention. At present, because the growing concern about environment issues, energy policy is receiving increased attention.

II.4. Organisation; structure and lines of communication

A formal written energy policy acts as a guidance of both management and the operating divisions of the industry. It acts also as a public expression of the industry's commitment to energy consumption and the environment protection.

For the uniform guidance of the actions of those who must make decisions regarding energy savings, policy must be formulated; disseminated and discussed.
It is in the best interest of the industry that its framework for energy policy be expressed in formal written declaration of commitment, accompanied by a set of stated objectives; an action plan for achieving them, and a clear specification of delegated responsibilities.

A thorough discussion of the policy while it is being developed and especially the feeling of participation by the people involved in will assist materially in its acceptance when it is promulgated by management.

Responsibility for formulating and implementing energy policy lies with the energy management committee which is accountable to the main board. This committee will be made up of representatives from each of the energy consuming sections within the industry.

The energy manager is responsible for coordinating energy management activities.
He/she makes a monthly report to his/her line manager, providing separate accounts of expenditure on energy consumption, and energy management activities. [15]

Through the line manager, he/she will make a quarterly report to the energy management committee, which will report regularly, and make an annual presentation, to the main board on energy consumption, and on energy management activities undertaken to reduce such consumption.

Formal communication on matters related to the control of energy consumption and energy management activities will be directed through the energy manager who will bring it to the attention of his/her line manager; other senior managers and to the energy management committee.

All energy management activities will be subject to periodic review. The energy manager will establish progress towards meeting objectives and the value for money of individual activities wherever possible. An annual audit of these activities will be prepared on behalf of the energy management committee and presented to the main board.

III. Energy efficient technologies in temporary accommodation

III.1. Introduction

No one can deny that technological progress during these two past decades has had a profound effect on construction industry. It has affected the energy consumption in dynamic ways and the industry's expenditure.

New technologies are being used to improve the conversion efficiency of devices used for services within buildings. For example, condensing boilers recover much of the latent heat from flue gas before they are released; more efficient forms of electric lamps have been designed; Heat pumps can make use of low temperature heat source, such as waste air, which have been ignored in the past. Accurate instruments, optimum controls cycles, and a basic understanding of causes and effects applied to system function can save energy.

An energy manager must understand how to incorporate new efficient technologies into plant operations. And plant engineers and managers are also expected to apply new technologies; keep their plants competitive and achieve high operating efficiencies. It is clear that applying proven energy efficiency technologies offer significant rewards.

A great deal should be said about plant operation and design of all types of buildings from the standpoint of how much glass; insulation; and lighting should be installed; what type of mechanical system to use; and what various ways to save energy; etc.
For example, better insulation; less glazing and deeper plan structures contributes sensibly in reducing heating requirements.

III.2. Lighting systems in a temporary accommodation

III.2.1. Daylighting system

Daylight is a source of illumination that uses solar energy. It provides contact with the natural environment outdoors and varies with the luminance of the sky. The light from the sky varies with the time of the day; with the season of the year and with the local weather. The most prominent characteristic of the daylight is its variability system.

When daylight enters the structure through windows, its continual variation provides a constantly changing pattern of space illumination. This could create special problems of glare control, direct sunlight control, and heat gain limitation. However, the use of energy efficient technologies such as high performance windows provides comfort and adequate natural lighting for interior spaces. It could admit maximum light and solar heat gain in winter months with minimum heat loss.

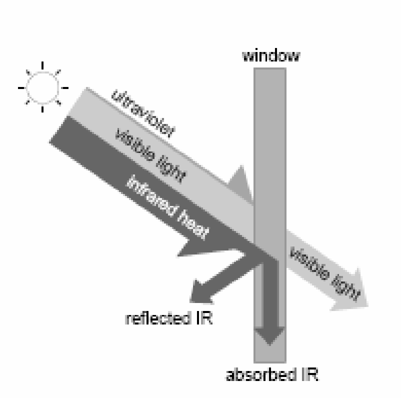
In hot weather, it is possible to control heat gain by keeping solar energy from entering the interior space while allowing reasonable visible light transmittance views and daylighting. Special glasses which prevent the transmission of most of heat radiation while admitting light transmission are now available. Table1 shows representative glass specifications.

Table1: Representative Glass Specifications [27]

Glass Type (product)	Glass Thickness (mm)	Visible Transmittance (% Daylight)	U-factor (Winter)	Solar Heat Gain Coefficient (SHGC)
Single Pane glass (standard clear)	6	89	1.09	0.81
Single White Laminated w/Heat Rejecting Coating	6	73	1.06	0.46
Double Pane Insulated (standard clear)	6	79	0.48	0.70
Double Bronze Reflective Glass (LOF Eclipse)	6	21	0.48	0.35
Triple Pane Insulated Glass (standard clear)	3	74	0.36	0.67
Pyrolitic Low-e Double Glass (LOF clear Low-e)	3	75	0.33	0.71
Soft-coat Low-e Double Glass w/Argon gas fill	6	73	0.26	0.57
High Efficiency Low-e (Solar screen 2000 VEI-2M™)	6	70	0.29	0.37
Suspended Coated Film	3	55	0.25	0.35
Suspended Coated Film w/ Argon gas fill	3	53	0.19	0.27

Glazing can use metallic layers of coating or tints to either absorb or reflect specific wavelengths in the solar spectrum. In this manner, desirable wavelengths in the visible spectrum that provide daylight are allowed to pass through the window while other wavelengths such as infrared (which provides heat) and ultraviolet (which can damage fabric) are reflected as it is shown on the figure1 below:

Figure1: *Characteristics of ideal window in hot weather* [22]



Thus, excess heat and damaging ultraviolet light can be reduced while still retaining the benefits of natural light.

It is now possible to have an excellent daylight at a table or some other workplane, and yet to be unable to see the sky because daylighting depends largely on light reflected by exterior surfaces and by interior surfaces.

Daylighting can provide the opportunity for both energy savings and improved visual comfort. The level of its integration into the design can have a profound influence on the energy consumption. To be effective, daylighting must meet the same visual performance criteria as artificial lighting in providing adequate levels and quality of task illumination.

III.2.1.1. Daylight factor

The amount of daylight inside a room can be measured by comparing it with the total daylight available outside the room. Their ratio called daylight factor, remains constant for a particular situation because the two parts of the ratio vary in the same manner as the sky changes.

The daylight factor is defined as the ratio of the illuminance on a given horizontal plane in a room, to the illuminance received at the same time on a horizontal plane exposed to unobstructed sky. It can be derived theoretically from the solid geometry of the building and its surroundings, and the optical properties of the glass and the reflecting surfaces.

The daylight factor is partly due to the light received through the window directly from the sky, and partly due to the light reflected from building opposite; from the ground outside; and from the internal surfaces of the buildings. It can be used with any exterior daylight illuminance, and indeed this is one of its advantages.

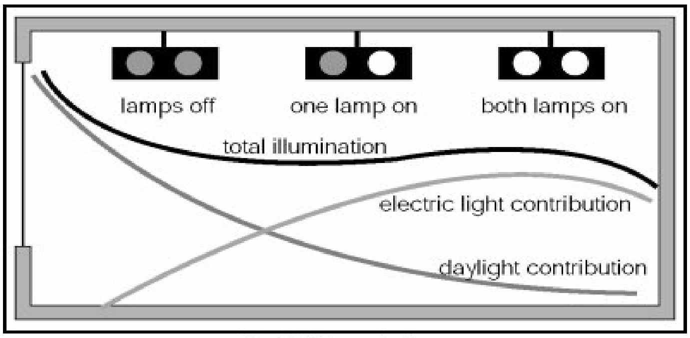
III.2.1.2. Combined daylight and electric light

Lighting should be planned according to the task performance needs. The task to be performed in each area of the building should be identified in order to coordinate the illumination requirements; the orientation of the tasks, and the location of the lighting equipment. All lighting whether electric or daylighting costs energy, so an energy conscious design dictates the use of only the amount of lighting required.

Working by natural light is most preferable. However, it is often difficult to provide adequate levels of natural illumination to all parts of the interior. In this case, daylight factor decreases rapidly with the depth of the office. And it would not be economical to increase the ceiling height merely for the purpose of extending the use of daylight.

The best solution to the above is to utilize daylight as far as possible in that part of office that is close to the windows, and use permanent supplementary artificial light for the interior. However, a high illuminance level wastes energy, and a low illuminance level may cause glare from the windows. In the case of low illuminance, additional electric lights are provided during daylight hours at the rear of the office to overcome the glare, and these are switched off at night time. This is shown in figure2:

Figure2: Artificial lighting and daylighting combination [28]



Form figure2, it is clear that the portion of the office near the windows is lit mainly by daylight; the rear of the office is mainly lit by the artificial light. The system of combined daylighting and artificial lighting contribute to the illumination of the central portion of the office.

The curves show relative light levels from both daylight and electric light. As the daylight level falls off with distance from window, the electric lighting makes up the difference so that total illumination is evenly maintained at design levels throughout the office. So, one can save electrical energy by controlling the artificial lighting with the photo-electric cells which senses changing daylight levels and switch lights on and off as necessary.

III.2.2. Artificial lighting

III.2.2.1. Introduction

Electric lighting system is typically composed of lamps; circuitry; switches; lighting controls; and luminaires. When considering the efficiency of the lighting system, the characteristics of all of these components must be included.

The quantity of the light of a certain surface is usually the primary consideration in the design of a lighting system. This quantity is specified by the density of luminous flux, or illuminance and measured in lumens/m^2.

Lighting system is an important area of energy conservation in buildings, as high energy efficient types of lamps such as compact fluorescent lamps and high pressure discharge lamps can be installed in existing buildings as well as in new buildings. The energy saved by a modernized lighting usually pays for the cost of installation within a shorter payback period.

It is desirable to replace existing unit with types that use a lower lamp lumen depreciation when relamping. For example, fluorescent lamps with better lamp lumen depreciation factors may cost more per unit, but the investment can be recovered by lower expenditures for energy and maintenance.

III.2.2.2. Luminaires

Luminaires are the fixtures into which the lamps are placed; they usually include a reflecting surface to direct the light toward the space to be lighted.
In the design of lighting installations, the choice of lamp must be combined with the choice of luminaires, as they usually absorb and redirect some of the luminous flux emitted by their associated lamps.

Luminaires may also serve a number of mechanical and electrical purposes such as positioning the lamps in space; protecting the lamps and controlling the lamps gear. Individual luminaires may be controlled by separate switches so that selected units can be independently turned on or off, or dimmed as needed to vary the illumination in space.

Physical properties that may be relevant in the choice of the luminaire include its electrical insulation; moisture resistance appearance and durability.

III.2.2.3. Energy efficient lamps

III.2.2.3.1. Compact Fluorescent Lamps

Fluorescent lamps are available in compact forms comparable in size to a traditional Tungsten filament lamp. Some of them have an electronic control gear incorporated inside the lamp so that they can be installed in a conventional light fitting to directly replace a Tungsten filament lamp; others have the control gear in the fitting.
Light is produced by a discharge arc passing through a gas in the tube. Ultra-violet rays are converted into visible light by interacting with a phosphor coating on the inside of the tube. Ballast is required in the circuit to regulate the current and the starting voltage.

A compact fluorescent lamp can replace an incandescent light source in particular applications. They are much more efficient than incandescent lamps and have up to 20 times longer life than some incandescent. They are long life; low-cost; high output and efficacy, and are available in an extremely wide range of sizes, colours; brightness. They also have a relative insensitivity to voltage fluctuation.

Three configurations are possible for the installation of the compact fluorescent lamps: dedicated; self-ballasted; and modular.

Dedicated compact fluorescent lamp systems are similar to full size fluorescent lighting systems in which ballast is hard wired to lamp holders within a laminaire.

Self-ballasted and modular compact fluorescent lamps products have screw bases designed for installation in medium screw base sockets, they typically replace incandescent lamps. A self-ballasted CFL contains a lamp and ballast as an inseparable unit. And a modular CFL product consists of screw base ballast with a replaceable lamp. The lamp and ballast connect together using a socket and base design that ensures compatibility of lamps and ballasts.

While most of modular types are operated in the preheat mode, the electronic ballasted lamps particularly rapid start mode and in principle could be dimmed. Operation of fluorescent lamps particularly rapid start tubes at frequencies more than $60H_Z$ has many beneficial effects. It increases lamp efficiency; decreases ballast cost, weight, size, and heat losses; and lowers maintenance. Operating fluorescent lamps at high frequency (20 to $30H_Z$) with solid state ballasts are 10 to 15% more efficacious than $60H_Z$ operation. [3]

All ballasts for indoor fixtures are required to be protected by an integral thermal-sensing device that will disconnect the ballast in the event of overheating. Overheating is caused by excessive voltage; excessive ambient temperature; or failure of a ballast component. These devices are either thermostatic (self-resetting) or fuse-type (self-destructive).

III.2.2.3.2.The efficiency of the T5 system

III.2.2.3.1. Technical data for the different T5 fluorescent lamps

In an effort to reduce lighting energy costs, T8 fluorescent lamp with electronic ballast was the standard for fixtures and could be retrofit in commercial office buildings, school and a substantial portion of industrial lighting. However, a new range of T5 fluorescent tubes was developed for higher system efficiency. T5 lamps are specially designed for higher frequency operation with electronic ballasts for higher efficiency and longer life. Their shorter length (50mm less than T8) and thinner diameter (16mm) enable lighting fittings designed for these tubes to fit into the common ceiling module systems without occupying additional space.

Improved technology and reduced dimensions inherent in the T5 tube can produce more efficient, external environmentally friendly lighting systems with luminaires which fit within the common European building modules, leading to easier fixing and installation.

For the reasons stated above, these two types of lighting (T8 and T5) systems were the most interesting, and were selected amongst many others. This research focused on them in order to see their impact on total energy consumption within a temporary accommodation.

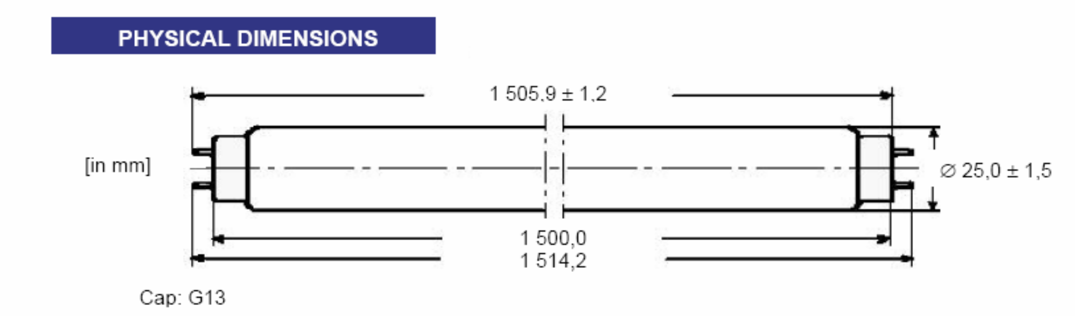
Table2: *Comparison of T5 fluorescent lamp's maximum luminous output at 35°C and the luminous output that applies at 25°C.*[20]

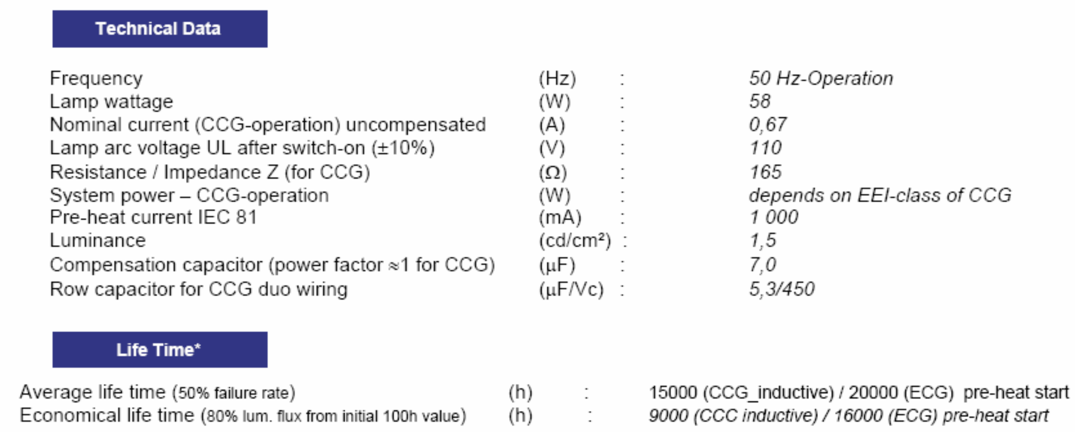
T5 lamp	Length	Design lumen (light source's luminous flux emitted at an ambient temperature of 25°C)	Luminous Efficacy (light source's max. luminous efficacy at an ambient T° of 35°C)	Max. Luminous Output (light source's luminous output emitted at an ambient T° of 35°C)
14W	549 mm	1200 lm	96 lm/W	1350 lm
21W	849 mm	1900 lm	100 lm/W	2100 lm
28W	1149 mm	2600 lm	104 lm/W	2900 lm
35W	1449 mm	3300 lm	104 lm/W	3650 lm
24W	549 mm	1750 lm	83 lm/W	2000 lm
39W	849 mm	3100 lm	90 lm/W	3500 lm
54W	1149 mm	4450 lm	93 lm/W	5000 lm
49W	1449 mm	4300 lm	100 lm/W	4900 lm
80W	1449mm	6150 lm	88 lm/W	7000 lm

The above table compares the T5 fluorescent lamp's maximum luminous output at 35°C and the luminous output that applies at 25°C under the condition that the fluorescent lamp is powered with reference ballast.

III.2.2.3.2.2. Technical data for the T8 L 58W [32]

Figure3: Physical dimensions of T8 L 58W





Technical Data

Frequency	(Hz)	:	*50 Hz-Operation*
Lamp wattage	(W)	:	*58*
Nominal current (CCG-operation) uncompensated	(A)	:	*0,67*
Lamp arc voltage UL after switch-on (±10%)	(V)	:	*110*
Resistance / Impedance Z (for CCG)	(Ω)	:	*165*
System power – CCG-operation	(W)	:	*depends on EEl-class of CCG*
Pre-heat current IEC 81	(mA)	:	*1 000*
Luminance	(cd/cm²)	:	*1,5*
Compensation capacitor (power factor ≈1 for CCG)	(µF)	:	*7,0*
Row capacitor for CCG duo wiring	(µF/Vc)	:	*5,3/450*

Life Time*

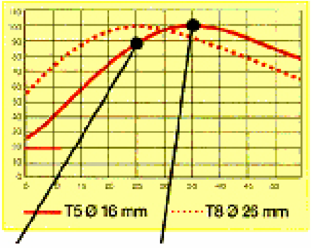
Average life time (50% failure rate)	(h)	:	15000 (CCG_inductive) / 20000 (ECG) pre-heat start
Economical life time (80% lum. flux from initial 100h value)	(h)	:	*9000 (CCC inductive) / 16000 (ECG) pre-heat start*

III.2.2.3.3. Comparison of the Efficiency for T5 system and T8 system

III.2.2.3.3.1. Relationship between relative luminous flux (%) and ambient temperature

The figure below (figure4) shows a relationship between relative luminous flux (%), and ambient temperature for T5 28W and T8 36W tubes. The relative luminous flux (%) and ambient temperature (°C) are located respectively on y axis and x axis of the figure. It is also indicated that the T5 tube was smaller in diameter (16mm) than the T8 tube (26mm). On the figure4, it appears that T5 fluorescent tube produces a relative higher luminous flux than the T8 fluorescent tube at an ambient temperature exceeding 30°C.

Figure4: Relative Luminous flux (%) [20]



The above figure (figure4) also shows how the luminous output increases (for T5 28W and for T8 36W) from an ambient temperature of 25°C to 35°C where the two fluorescent lamps emit their maximum luminous output with ballasts reference.

Table3: *Comparison of luminance between T5 and T8 fluorescent tubes* [14]

Type of Lamp	Average lamp luminance
T8 36W	11000 cd/m^2
T8 58W	14000 cd/m^2
T5 28W	17000 cd/m^2
T5 49W	23000 cd/m^2
T5 80W	37000 cd/m^2

The T5 tube produces higher luminance than the T8 tube as it is shown in the table3, and this has to be considered in designing a new luminaire.

Table4: *Comparison between T5 and T8 mirror louvre fixture*

Type of luminaire	T8 luminaire with HF ballast 1x36W/T8	T5 luminaire with HF ballast 1x28W/T5
Light output ratio	61%	76%
System wattage	36+10 = 46W	28+2.5 = 30.5W
Luminous flux-lamp	3200 lm	2900 lm
Luminous flux-luminaire	1950 lm	2200 lm
Luminous efficacy	54 lm/W	72 lm/W
Energy saving	**0%**	**33%**

The above table shows that the luminous efficacy can increase from 54lm/W to 72lm/W or by about 35% for luminaires provided with the more effective reflector material which has been adapted for the new T5 fluorescent tube. This improvement results: to the lamp system contribution of a maximum of 7% for a HF ballast, to the improved aluminium reflectors and louvres of 10%, to the higher lamp luminous efficacy of 10% (at 35°C), and to the improved efficacy due to smaller lamp diameter (from 26mm to 16mm).

Table5: *Comparison between T5 and T8 mirror louvre fixture*

Type of Luminaire	T8 Luminaire without HF ballast 1x36W/T8	T8 Luminaire with HF ballast 1x36W/T8	T5 Luminaire with HF ballast 1x28W/T5
Light output ratio	60%	61%	76%
System wattage	36+10 = 46W	32+4 = 36W	28+2.5 = 30.5W
Luminous flux-lamp	3350 lm	3200 lm	2900 lm
Luminous flux-luminaire	2010 lm	1950 lm	2200 lm
Luminous efficacy	44 lm/W	54 lm/W	72 lm/W
Energy saving	**0%**	**23%**	**64%**

Table5 compares the effect of luminous efficacy of the equivalent T8 luminaire with or without HF ballasts, and the luminaire which has been adapted for the T5 fluorescent tube. The comparison between the T8 luminaire without HF ballast (44 lm/W), and the T5 luminaire (72 lm/W) shows an increase in luminous efficacy of 65%. Equally changing the ballast used with the T8 fluorescent tube from conventional to HF produces an increase in luminous efficacy of about 25%.[14]

Table6: *Comparison between T5 and T8 with conventional ballast* [14]

Type of lamp	Ballast losses	Luminous flux	Efficacy	Increase in efficacy
T8 36W	10W	3350 lm	89 lm/W	0%
T5 28W	2.5W	2900 lm	95 lm/W	30%

By comparing the T5 and T8 with conventional ballast, the above table shows that T5 in itself emits around 30% more light than the T8 with conventional ballast.

Table7: *Comparison between T5 and T8 with HF ballast* [14]

Type of lamp	Ballast losses	Luminous flux	Efficacy	Increase in efficacy
T8 36W	4W	3200 lm	89 lm/W	0%
T5 28W	2.5W	2900 lm	95 lm/W	7%

The above table shows that the T5 system with the luminaire which has been adapted for the new T5 fluorescent tube emits only around 7% more light than the T8 with HF ballast.

III.2.2.3.4. Benefits of using T5 fluorescent tubes on lighting systems

The improved technology and reduced dimensions inherent in the T5 fluorescent tube can produce more lighting systems with luminaires which fit exactly into the standard ceiling grid without occupying additional adjacent space.

The T5 lamps are specially designed for high frequency operation with electronic ballasts; for higher energy efficiency; and longer economic time due to lower lumen depreciation. Compared to T8 lamps, their reduction in tube diameter, and tube length give more luminaire design capabilities, and they can easily fit into the common ceiling module systems. Also, the T5 fluorescent lamps are more environmentally friendly because they contain less mercury than the T8 fluorescent lamps. Consequently, less mercury is disposed off, and emitted to the environment during their replacement.

The efficacy of the T5 luminaires depends on the type and design of luminaire. And the luminaire efficacy depends on the ambient temperature within the luminaire and whether the luminaire is equipped with a reflector or a louvre.

The luminaire designed for the T5 fluorescent tubes is provided with a mirror-reflector giving improved reflector quality and higher lighter output ratio. The improved reflectors permit a more precise control of the light from the fluorescent tubes.

Although the T5 luminaire is more expensive, the higher costs of the T5 luminaire could be easily compensated via enhanced performance such as high efficacy; high utilisation factor; long lamp life; less heat dissipation; reduced energy consumption and demand charge; etc.

III.2.2.4. Lighting controls: methods and equipments

III.2.2.4.1. Introduction

The energy crisis has caused users to look for ways to reduce power consumption. One method of controlling light output is to exploit daylight more efficiently. Effective daylighting has a strong potential for reducing energy demand in non-domestic building. Daylighting approach allows a more flexible building façade design strategy and enhances a more energy efficient and greener building development.

Energy savings resulting from daylighting means not only low electric lighting and reduced peak electric lighting demands, but also reduced cooling loads and potential for smaller heating; ventilating and air conditioning (HVAC) plants. Even with adequate daylight illumination, electric lighting must usually be provided for times when the availability of natural light is not enough.

In order to save energy, a control system is needed to switch off the artificial lighting when the daylighting is sufficient. The control may be manual or automatic. Manual controls are simpler and less expensive, but not as reliable as automatic controls. Automatic controls normally consist of photoelectric switches that automatically dim or turn off unnecessary electric lighting when daylighting is sufficient, and then turn them back on when needed.

III.2.2.4.2. Electric lighting control methods

III.2.2.4.2.1. Control of lighting power consumption

Some simplified methods have been developed and are found to give satisfactory results. For example, energy consumption for illumination can be effectively reduced by 15% in most existing building by turning off lights when they are not needed; in paying more attention to matching the amount of lighting used to do the job being done; and by using lights that require less energy.[1]

Lights in unoccupied areas should be dimmed or shut off. To do so, a sufficient number of key switches should be installed where opportunities exist for their effective use so that all lights not needed for periods of time during the day can be turned off. A careful analysis of all occupied rooms, the number of occupants, their activities in each space and the length of time each space is occupied, will reveal many opportunities for reducing the intensity of illumination or shutting off lights completely.

Another method is to replace lamps with lamps of smaller wattage or lamps of greater efficiency. However, on this method, removal of only one lamp from a two ballast circuit can affect ballast life seriously and can cause immediate failure. If both lamps are removed from a two lamps ballast circuit, a small amount of power is still consumed as the ballast draws magnetizing current. In this case ballast should be disconnected when lamps are removed.

It is advisable when relamping, to consider the existing windows that can be used to reduce electrical lighting requirements, and to review existing lighting system, taking into account individual fixtures that can be fully disconnected or lamps that can be fully removed to reduce wattage of an individual fixture. It is also required to select a light source that has the highest efficiency, compatible with other systems requirements such as lower wattage; life; colour rendition; etc.

Individual luminares should be selected and controlled by separate switches so that selected units can be independently turned on or off; or dimmed as needed to vary the illumination in the area.

III.2.2.4.2.2. Maintenance and depreciation of lamps

Lamps deteriorate as they get older. They produce less light, and eventually they fail. Even if all lamps are installed at the same time, they will fail at different time because the average life of lamp is influenced by the frequency of switching on and off; by the ambient temperature; by the adjustment of the control gear; and by the type of ballast.
It is more economic for large offices to allow a few failed lamps in position, and to replace all lamps together on regular schedule.

The loss of light can be appreciable if the lamps are not cleaned. Dust accumulation is a special problem with lamps in indirect luminares that reflect the light upwards, particularly for the fluorescent lamps that present long horizontal tubes to the dust particles.

III.2.2.4.3. Lighting control equipments

III.2.2.4.3.1. Introduction

Artificial lighting is one of the major electricity consuming items in a temporary accommodation. In recent years, there has been an increasing interest in incorporating daylight in the architectural and building designs to save building energy. The accurate instruments, optimum control cycles, and a basic understanding of cause and effect applied to the system functions can save energy.

New technologies, for example, time switches and photoelectric controls have been developed to improve the efficient use of daylight.

Daylight responsive dimming systems consist of three major components: photo-sensor; lighting controller; and electronic dimming ballast. It consists of maintaining target illuminance levels at the workplane regardless of the amount of daylight available in the interior space. To satisfy such a purpose, the electric light output is continuously adjusted based on the changes in available daylight measured by photo-sensors. This system is used to improve both the quantity and the quality of the visual environment; and can reduce significantly electric lighting requirement where daylight can serve as a useful source of illumination.

III.2.2.4.3.2. Sensors and control systems

Lighting control can be achieved by different methods such as timer control; daylight control; occupation control; and local switching control. The table below shows eligible lighting control equipments.

Table8: *Eligible lighting control equipments* [29]

Type	Function
Time controller	Automatic time switch device to switch lighting “on” and /or “off” at predetermined times or intervals.
Presence detector & controller	Automatic device detecting occupancy or movement in an area to switch lighting “on” and “off” in line with occupancy needs.
Daylight detection & switching controller	Device to monitor daylight availability in an area and control the switching of lighting “on” and “off” according to the occupants needs.
Daylight detection & regulation controller	Device to monitor daylight availability in an area and regulate the light output of the electric lighting to provide only sufficient artificial lighting to supplement the daylight component. Generally used in conjunction with high frequency fluorescent luminaries equipped with dimmable ballasts.
Central control unit	Control unit for an overall managed lighting control system utilising some or all of the types of control elements listed above.

The timer control method is applied by setting timers to switch off lighting for periods of known inactivity, such as the end of the working day. This system use clock sensors to regulate the illumination as a function of time.

The daylight control method use photocell sensors that measure the illumination level, and switch lights on and off, or dim lights according to the level of daylight detected in a room. The occupation control method use personnel sensors to detect whether a space is occupied by sensing the noise or the motion of the occupant. The sensors turn lighting on when there is someone in the room and off again after a time delay if there is nobody in the room. The local switching method is about switching on lights only in the part of the room which is being occupied.

To maintain target lighting levels at the workplane in response to the changes in the amount of available daylight, a signal is first measured by photo-sensors, which should represent workplane illuminance values. Photo-sensors are used to measure the light intensity. They can detect both the reflected electric light as well as daylight to provide a close-loop control dimming system. The lighting level received can be sent to a dimming controller, which varies the light output of the fluorescent lamps accordingly via the dimmable electronic ballasts. Other sensors can be used to record the transmitted daylight.

The digital electronic control gear enables the fluorescent lamps to be dimmed from1 to 100% of their luminous flux. The brightness of the fluorescent fittings can be used to evaluate daylighting performance of the space lightened. The zero brightness reading indicates savings of a standard on-off, while 100% shows the system under full operation. Daylight-linked automatic lighting control system can provide excellent energy savings.

III.2.2.4.3.3. Lighting control: Switches/relays

An on-off control is designed to switch the artificial lighting on and off automatically as the daylight level falls and rises through a predetermined level. However, one problem with this control type is the frequency of the switching on and off, particularly during unstable weather conditions when daylight levels are fluctuating around the switching illuminance. This can annoy occupants and reduce lamp life.

There exist several variants to the on-off control, namely differential switching; time delay and solar reset to reduce the number of switching operations. A differential switching has two switching illuminance: one at which the light should switched off; and another at which the light are switched on.

A time delay means that there is no further switching until the lapse of a preset amount of time after the last switching or after reaching a preset target daylight illuminance value. In solar reset switching, the lighting can only be switched off at certain set times of the day. Although an automatic dimming control system is adopted for daylight space lighting, the logged brightness reading can be used to determine the number of switching operations and the energy saving of a standard on-off control. To reduce the annoying rapid switching on and off of lights differential switching should be required in a practical system.

III.2.2.5. Lighting design and measurement

The lighting system design may specify newer types of fixtures that will give the same amount of illumination as incandescent lighting with less energy consumption. It may be possible to reduce wattage of lamps to each fixture, and in some cases the number of fixtures in services, without a reduction in allowable illumination.

The quantity of lights on a certain surface is usually the primary consideration in the design of lighting system. This quantity is specified by the density of luminous flux, or illuminance; and a measured in lumens/m^2.

The type of lighting suitable for a particular building should be linked to other design decisions for the building such as the basic plane shape; the type and extent of windows, and the type of heating and cooling. Light abatement can be included in the design to minimize the energy consumption by specifying the correct type of lighting.

III.2.2.5.1. Measurement of lighting

Light is one form of energy and could be measured by the standards units of energy. But the effect of light on human environment depends upon the sensitivity of the eye, and special set of units has therefore been developed for the measurement of light and its effects.

III.2.2.5.2. Lighting design

Illuminance is affected by the distance and the angles between the illuminated surface and the light source, and by the reflectance of the surrounding surfaces.
In an interior building where there is many light sources and several reflecting surfaces, the repeated combination of these effects makes calculations difficult if basic formula is used. However, by understanding the basics of lighting design, several ways to improve the efficiency of lighting systems become more apparent.

There are two common lighting methods that have been developed and are found to give satisfactory results. These are the lumen method and the point by point method.

The point by point method calculates the lighting requirements for the task in question.
The lumen method is the most widely used approach to the determination of lighting layout that will provide a service illumination on the working plane from lamps overhead in a substantially regular pattern.
The lumen method uses the following formula:

$$N = \frac{E * A}{F * U * L_1 * L_2} \quad [2]$$

Where:

N = number of lamp fittings required

E = illumination required at working plane

A = areas of the room

F = lumens output per lamp (found in manufacture's catalogue)

U = coefficient of utilization (can be found in manufacture's catalogue)

L_1 = lamp depreciation factor (can be found in manufacture's catalogue)

L_2 = luminaire (fixture) dirt depreciation factor

When considering the efficiency of the lighting system, the characteristics of all of the components must be included.

III.2.2.5.2.1. Lighting components characteristics

The luminaire (fixture) dirt depreciation factor (L_2) takes into account the effect of dirt accumulation on a luminaire, and varies with the type of luminaire and the atmosphere in which it is operated.

The lamp depreciation factor (L_1) takes into account the deterioration of lamp output with time. It is specified by the manufacturer on the basis of testing programs.

The coefficient of utilisation (U) indicates how efficiently the luminaire illuminates the working plane. It is related to the room geometry; and the reflectance, as well as the characteristics of the luminaire.

The IES lighting handbook contains U values for various types of the luminaries and room characteristics.

The coefficient of performance is the ratio between the total flux in lumens reaching the working plane to the total flux in lumens generated by the lamp.

It takes into account of light absorbed or reflected by walls; ceiling and the fixture itself

The light loss factor (LLF) takes into account of deterioration of the lamp with time and accumulation of dirt. It could be found from the manufacture's catalogue.

LLF = Illuminance provided at some given time / Initial illuminance

LLF = lamp maintenance factor*luminance maintenance factor*room maintenance factor

Maintenance factor (M) takes into account the light loss due to dirt accumulation on the fittings and room surfaces

III.3. Heating systems in a temporary accommodation

III.3.1. Space heating equipments

III.3.1.1. Unit heaters

Heaters come in a wide variety of models, they may be permanently installed or portable; and they may employ a combination of radiation; natural convection and force convection to transfer the heat produced. They furnish directly warm-air to the space in which they are installed, and obtain themselves their heat from steam; hot water; electricity; and also from direct combustion of gas or oil.

Permanent installed heaters, whether fuel is supplied with a special electrical circuit; a gas pipe or a supply of solid fuel, must be sized correctly for the heat load.

Oil and gas heaters that receive heat from direct combustion, require also the electricity for ignition, and to operate a fan. In that case, oil or gas is piped to the heating element, and this latter requires a flue or chimney to take away the combustion products, especially, to the outside the atmosphere. The combustion products from natural gas are sometimes allowed to be released into the heated space if it is well ventilated.

III.3.1.2. Heat sources for central heating systems

Heater installation in each room of a building is required for space heating. However, it is preferable to use a central heat source with a system of heat transfer to the rooms.
In central heating system, heat generating equipment is used for air or water heating, or for steam generation, which is then conveys the heat to the various rooms and spaces throughout the building.

The heating system equipment using air as the primary distribution fluid is known as a furnace. And, if the fluid is a liquid or a steam, the heating device is a boiler. These terms generally refer to the equipment using fuel or electricity as the energy source, but are sometimes used in reference to alternatives such as solar furnaces or heat recovery boilers.

The fuel for a furnace or a boiler for a central heating system can be oil; gas; solid fuel; or electricity. By using one of the heat transfer processes, the heat source (fuel) transfers its thermal energy to the fluid, increases the fluid temperature or changes its state from a liquid to a gas.

There is no need to use a central heating system with electric resistance heating because electricity can be easily conveyed directly to the space to be heated, and can therefore be converted into heat by a wide variety of heaters. Electric heating equipment usually requires less maintenance and offers the opportunity to eliminate the central heat generating stage, so that heating with electrical energy can considerably reduce the first cost of the system.

Nonetheless, using electrical heating is more expensive than that for other fuels due to the high cost of the electricity. But, a more economical use of electric energy is a heat pump.

III.3.1.2.1. Furnaces

A furnace is a heating device, which use air as the primary distribution fluid in central heating system. It may be available in up flow; down flow; horizontal and in other heated air directions to the applications requirements.
The central heating appliances include generally warm-air furnaces, and steam or water boilers. The warm-air furnaces are of different types and depend on the force required to move the combustion products, and on the force required to move supply and return air. It also depends on the location in the building and the efficiency required.

III.3.1.2.1.1. Natural gas furnaces

The natural gas is the most common fuel supplied for residential heating, and the central system forced air furnace is the most common way of heating with natural gas. This type of furnace is equipped with a blower to circulate air through the furnace enclosure, over the heat exchanger, and through the ductwork distribution system.

The main components of such a furnace are: casing; heat exchangers; combustion system including burners and controls; forced draft; induced draft or draft hood; circulating air blower and motor; air filter; and other accessories such as a humidifier; electronic air cleaner; air conditioning coil; or a combination of these elements.

The force to move the combustion products can be supplied by the natural buoyancy of hot combustion products in a natural draft furnace; by a blower in a forced-draft or induced draft-furnace; or the thermal expansion forces in a pulse combustion furnace. If the space to be heated is closed and/or above the furnace, the force to move heated and supply and return air can be supplied by the natural buoyancy of heated air in a gravity furnace. That force can also be supplied by a blower in a forced air furnace.

Standard indoor furnaces are generally made of cold-rolled steel. If furnace is exposed to clean air, and the heat exchanger remains dry, this material has a long life and does not easily corrode. The air combustion contaminated by substances such as cleaning solvents; and halogenated hydrocarbon refrigerants can cause problems of heat exchanger corrosion and failure. Common corrosion resistant materials include aluminized steel; ceramic coated; cold-rolled steel, and stainless steel.

Furnace controls include an ignition device; gas valve; fan switch; limit switch; and other components specified by the manufacturer. An air filter in a forced air furnace, remove dust from the air that could reduce the effectiveness of the blower and heat exchangers.

III.3.1.2.1.2. Electric furnaces

A resistance type heating unit, heats the circulating air directly, or through a metal sheath enclosing the resistance element.

Although the efficiency of an electric furnace is high, it can be more expensive long term heating option, because the electricity is relatively expensive form of energy, and due to heat losses through its ducts. The operating cost may be reduced significantly by using a heat pump in place of a straight electric resistance furnace.

The building's air is delivered to the furnace through return ducts, and heated air is delivered back to the room through supply ducts. If these ducts run through unheated areas, they lose some of their heat through air leakage as well as heat radiation and convection from the duct's surface. A fan is used to maintain the flow, and in most installations the air is filtered before passing over the hot surfaces of the furnace. The furnace may be controlled manually or by a thermostat located in the return air path.

In an electric furnace, blower (large fan) move air over a group of electric resistance coils. The furnace's heating elements activate in stages to avoid overloading the building electrical system. If a dirty filter is blocking air flow or if the blower fails, a built-in thermostat also called limit controller may b used to shut the furnace off, as well as to prevent a overheating.

III.3.1.2.2. Boilers

A boiler is a central heating device, which use water in the form of liquid or steam as a primary distribution fluid in central heating system. It is a pressure vessel heat exchanger made in cast-iron; steel or copper, and designed with fuel burning devices and other equipments to burn fossil fuels. It also transfers heat from electrical resistance elements to the fluid or by a direct action of electrodes on the fluid.

The combustion space of some boilers is called furnace, and the area of fluid-backed surface exposed to the combustion products, or to the fire side surface is the boiler heating surface. However, in the case of electric boilers, electrodes are immersed in boiler water and the heating surface is the surface of electric elements. The design of electric boilers is largely determined by the shape and the heat produced by electric heating units used.

A system of pipes connected to the boiler delivers heated fluid to the point of use and returns the cooled fluid to the boiler. Boilers may be designed to burn various grades of fuel oil; various types of fuel gas; coal; etc, or to operate as electric boilers.
A boiler designed for one specific fuel type may not be convertible to another type of fuel. Boilers selection should be based on the following parameters:

- Net boiler output capacity
- Total heat transfer surface
- Water content
- Auxiliary power requirements
- Internal water flow patterns
- Cleaning provisions for all heat transfer surfaces
- Operational efficiency
- Space requirements and piping arrangement
- Water treatment requirements

III.3.1.2.2.1. Energy efficient condensing boilers

High efficient condensing boilers convert around 90% of their fuel into heat, compared to 79% for conventional types. They have a larger, or sometimes an additional heat exchanger. This heat exchanger captures much of the energy otherwise lost through the flue. The flue gases are cooled to the point where water vapour, produced during combustion condenses. Hence the name: “Condensing Boiler”. If the right heating controls are installed with high efficiency condensing boilers, 40% on the fuel bill could be saved. [31]

III.3.1.2.3. Heat pumps

III.3.1.2.3.1. Introduction

Many modern buildings require simultaneously heating and cooling for prolonged periods during occupancy. However, the rising cost of energy is having an inflationary effect on energy cost consumption. One obvious way to reduce energy costs is to use energy efficient equipments wherever possible and to recycle heat wherever possible.

The heat pump is well suitable for such applications, and frequently shows a considerable saving in operating cost over other heating equipments. Innovative use of heat pump principles may give considerable energy savings and more satisfactory human comfort than other systems.

III.3.1.2.3.2. Definition and heat pump's function

A heat pump is an electrical device that extracts heat from a low temperature source and transfers it to a higher temperature, so that it may be used for space or water heating. Heat pumps transfer heat by circulating a substance called refrigerant through a cycle of evaporation and condensation.

A compressor pumps the refrigerant between two heat exchangers coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed en route to the other coil, where it condenses at high pressure. At this point it releases the heat it absorbed earlier in the cycle.

The low temperature heat source may be from water; air; or soil which surrounds the evaporator. The heat pump always give out more energy than the energy used for driving it, and it is a means of using electrical energy to it advantage.

The objective of a heat pump is to maintain a heated space at a high temperature. This is accomplished by absorbing heat from a low temperature source such as a well or cold outside air in winter, and supply this heat to the high temperature medium such as a house.

The heat pump cycle is fully reversible, and heat pumps can provide year-round climate control for space-heating in winter, and cooling and dehumidifying in summer. Since the ground and air outside always contain some heat, a heat pump can supply heat to a building even on cold winter days. In fact, air at -18°C contains about 85% of heat it contained at 21°C.

The measure of performance of a heat pump is expressed in terms of the COP_{HP}, defined as:

$$COP_{HP} = \frac{DesiredOutput}{\mathrm{Re}\,quiredInput} = \frac{Q_H}{W_{net,in}}$$

It can also be expressed as: $COP_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \frac{Q_L}{Q_H}}$

Most existing heat pumps use cold outside air as heat source in winter. However, the major problem with air-source system is frosting, which occurs when the temperature falls to near or bellow the freezing point. The frost accumulation on the evaporator coils is highly undesirable since it seriously disrupts heat transfer, and therefore, the efficiency drops significantly. It is necessary to use a separate boost heaters to supplement the heat pumps in very cold weather. Most-air source heat pumps require a supplementary heating system such as electric resistance heaters; or an oil or gas furnace.

In general, using a heat pump alone to meet all heating systems may not be economical. However, if used in conjunction with a supplementary form of heating, such as an oil; gas or electric furnace, a heat pump can provide reliable and economic heating in winter and cooling in summer. If an oil or electric heating system already exists, installing a heat pump may be an effective way to reduce the energy costs.

Water-source systems usually use well water from depth up to 80m in the temperature range of 5 to 18°C, and they do not have a frosting problem. They typically have higher coefficient of performance (COP), but are more complex and require easy access to a large body of water such as under-ground water.

Ground-source systems require the burial pipes deep in the ground where the soil temperature is relatively constant. Those heat pumps are more expensive to install, but more efficient than air source heat pumps.

III.3.1.2.3.3. Heat pump operating costs

The operating costs of a heat pump can be lower than those of other heating systems, particularly electric or oil heating systems. However, a number of factors affecting heating costs must be considered when running a heat pump. These include the cost of electricity and other fuels; the location of space heating and the severity of winter climate; the type; and the efficiency and the coefficient of performance.

By running a heat pump, less gas or oil is used, but more electricity is required. If the electricity is very expensive, the operating cost may be higher. So, a careful analysis based on relative costs of different energy sources is needed, in order to determine the total savings, and the payback period. Heat pumps have a service life between 15 to 25 years depending on the heat pump type. For example ground-source heat pumps have life expectancy higher than that for air-source heat pumps, because the compressor of ground-source heat pumps has less thermal and mechanical stress and it is protected from the environment.

III.3.2. Heating controls

III.3.2.1. Introduction

Space heating or central heating systems can run efficiently by providing warm and comfortable building at a surprisingly low cost. The overall effectiveness of a heating system depends on high efficiency heating equipment that ensures little potential heat is wasted, and on good controls designed to ensure that the heating equipment is only working when required.

Installing new controls devices, as well as making the heating system more flexible can save energy. This because better controls let heating systems react to changes in temperature, provide different levels of heat in different rooms, and switch hot water on and off at whatever times are specified.

Good heating control require a variety of equipments that operate mostly automatically such as sensors; actuators; switches; indicators; etc.

III.3.2.2. Automatic heating control equipments

III.3.2.2.1. A timer or programmer

It is a device that allows the time settings for space heating and hot water to be full independent. Some models switch the central heating and domestic hot water on and off, either at the same time or at different times.

A programmer set the on and off time periods to suit the lifestyle, and can set the heating and hot water to run continuously; to run under the chosen on and off heating periods; or to be permanently off.

When the central heating is running continuously or the heating is left on all day, the energy is being wasted. In spring and autumn for example, there is no need to keep the heating on all day.

With a seven day timer, it is possible to set a different heating pattern for weekdays and weekends. Some timers allow different patterns for each day of the week; this can be useful for those temporarily occupied rooms or offices such as conferences rooms.

III.3.2.2.2. A room thermostat

A room thermostat measures the air temperature within the building and switches the heating system on and off as needed. It senses the air temperature; switches on the heating system when the air temperature falls bellow the thermostat setting; and switches it off once this set temperature has been reached.

The room thermostat doesn't affect neither how quickly the room heats up nor cools down, but the heating up depends on the design of the heating system for example, the size of the boiler and radiators.

Turning a room thermostat to a lower setting results in the room being controlled at a lower temperature (generally 18°C), and saves energy. Any further adjustment above this setting result in energy wastage and cost more money.

III.3.2.2.3. A programmable room thermostat

A programmable room thermostat is a combined programmer and room thermostat which allows the user to set different periods with different target temperatures for space heating, usually in a daily or weekly cycle. This device lets users choose the time they want the heating to be on, and to determine the target temperature to be reached while it is on. It allows the user to select different temperatures in a particular building at different times of the day or days of the week to meet particular heating requirements.

One programmable room thermostat can be used to control the whole building if the heating system is carried by a boiler with radiators. However, if different temperatures in individual rooms are required, the thermostatic radiator valves (TRV) should be installed on individual radiators.

III.3.2.2.4. A cylinder thermostat

A cylinder thermostat measures the temperature of the hot water cylinder, and switches on and off the heat supply from the boiler to the hot water cylinder. It operates by sensing the temperature of water inside the cylinder; switching on the water heating when the temperature falls below the thermostat setting, and off when this temperature set has been reached.

The water heating up depends on the heating system design. For example, it depends on the size of the boiler and the heat exchanger inside the cylinder. The cylinder thermostat has a temperature scale marked on it, and should be set at temperature between 60°C and 65°C. This range of temperature is high enough to kill harmful bacteria in water. Further raising temperature of the stored hot water in cylinder, may result in energy wastage.

III.3.2.2.5. Thermostatic radiator valves (TRV)

A thermostatic radiator valve (TRV) has an air temperature sensor which is used to control the heat output from the radiator by adjusting the water flow. It may be fixed to each heat emitter, and operates when the correct air temperature is reached by expanding and closing the valves. These control valves provide individual room control of heat output; and windows no longer need to be left open to maintain comfort in overheated rooms.

Thermostatic radiator valves switch individual radiators on and off, depending on how warm the room they are located in is. These devices sense the air temperature around them, and provide good local temperature control in individual rooms by regulating the flow of water through the radiator where they are fitted to. They are added to the heating system in order to provide extra benefits of individual room temperature control, and greater energy savings.

The thermostatic radiator valves should be used with a room thermostat or a boiler energy control in domestic control, to ensure boiler interlock. However, they shouldn’t be installed in the same room as the room thermostat or a programmable room thermostat.

When fitting several TRV, it is essential to fit a bypass and a regulating valve to ensure that the flow rate through the boiler is maintained at a constant rate.

III.3.2.1.6. An automatic bypass valve

This device controls water flow in accordance with the water pressure across it, and is used to maintain a minimum flow rate through the boiler and to limit circulation pressure when alternative water paths are closed. A bypass circuit must be installed if the boiler manufacturer specifies that a minimum flow rate has to be maintained while the boiler is firing. The installed bypass circuit must then include an automatic bypass valve.

III.3.3. Building design for rational energy use on heating system

III.3.3.1. Building envelope

A building envelope includes everything that separates the interior of the building from the outdoor environment, including windows; walls; foundation basement slab; ceiling; roof; and insulation.

It can be analysed for its heat flow characteristics including its ability to control heat gain and heat loss by its construction; orientation and the use of particular building materials. The transmission of heat through the envelope (glass, walls, roof, and door) is a function of conductive characteristics; surface area; and the difference in dry-bulb temperature between inside and outside.

Today, a wide variety of alternative materials is being used to construct buildings; many of them have energy efficiency as well as environmental benefits. To assess the envelope ability for controlling thermal transfer and regulating interior conditions for thermal comfort, the following factors must be considered:

- Heat losses by transmission through the fabric of the building
- Heat losses by air leakage around openings and through fabric
- Control systems for space heating and hot water
- Heat losses from vessels and pipes used for hot water
- Heat losses from hot water pipes and hot air ducts used for space heating
- Energy efficient lighting sources and switching for the building

So, by taking advantages of innovative technology and new design concepts, perfects comfort conditions in buildings could be achieved at little or no additional cost.

One option for reducing the amount of energy consumed in space heating is to increase the thermal resistance of the envelope. This barrier-walls approach requires more material (such as insulation) in construction, and the extra labor. Once this approach is applied, the energy conservation required could be achieved without making demands on the users to change their living patterns.

While it is possible to implement energy conservation measures in new building by using correct construction methods at little or no additional cost, there are major changes that can be made in existing building such as replacing windows with insulated walls or increasing the thickness and insulation of walls or roofs. This also involves either a costly new exterior surface with changes in the frames of all openings, or a new interior surface with changes at electrical outlets, counters or fixtures adjacent to exterior walls, and again at all windows and doors frames.

These modifications to existing building require an additional investment to achieve the desired results, and the costs vary with the type of the building. In most cases, significant results in annual energy savings can be achieved. Such savings should be considered in terms of their present value to determine their true worth and the payback periods over the life of the building.

III.3.3.1.1. Air infiltration/Ventilation rate

Air infiltration or air leakage is outside air that infiltrate into a building through various leakage paths, such as dry lining masonry walls; timber frame construction; windows; doors and roof lights in building fabric.

This outside air in form of infiltration and ventilation imposes a heating or cooling load on the conditioned space and on the mechanical systems that control the temperature and the humidity conditions.

Ventilation is a fresh air that enters a building in a controlled manner to exhaust excess moisture and reduce odours and stuffiness, while air infiltration arises from controlled and uncontrolled leakage through cracks and openings. The amount of fresh air needed to be supplied to a space depends with the occupancy level, and the activities carried within that space. For example, Table 9 shows the minimum recommended fresh air supply rates that should be used to control body odour levels in rooms with sedentary occupants.

Table9: *Recommended fresh air supply rates for sedentary occupants* [16]

Conditions	Recommended outdoor air supply rate
With no smoking	8 l/sec per person
With some smoking	16 l/sec per person
With heavy smoking	24 l/sec per person
With very heavy smoking	32 l/sec per person

The infiltration rate is one of the most difficult quantities to accurately estimate. The difficulty lies in the wide variation in type; quality of construction; shape, and location of the building; the type of heating system; and the design variation in window and door construction. However, the rates of probable infiltration occurring under average conditions in residences are estimated (according to CIBSE guide). These are given in the table10:

Table10: *Air changes occurring under average conditions in residences* [11]

Kind of room	Number of air changes/h
Rooms with no windows or exterior doors	0.5
Rooms with windows or exterior doors on one side	1
Rooms with windows or exterior doors on two sides	1.5
Rooms with windows or exterior doors on three sides	2
Entrance halls	2

The building regulations requires that air leakage through building envelope to be limited as far as is practicable, by preventive measures such as sealing gaps with windows and doors; sealing gaps at junctions with walls, floors, and ceilings; complete sealing of vapour control membranes; etc.

III.3.3.1.2. Moisture control

Occupants of buildings, certain appliances; and plumbing equipments generate moisture that is carried in air as vapour. As moisture vapour moves from a warm interior through construction materials to a colder surface, the moisture condense as water which could damage the building.

When moist air comes in contact with a cold surface, some of the moisture may leave the air and become liquid or condense. If it condenses inside a wall, or in attic, it can cause a number of problems.

If the moisture produced in building condense in the insulation of walls; floors; and ceilings, the insulation become less effective. This is because wet insulation is less effective in preventing heat loss, or the additional weight could also cause structural damage by exceeding the weight bearing capacity of the ceiling.

By locating vapour retarders on the side of the insulation toward the warm area, moisture vapour is kept away from cold surfaces on which it might condense to liquid water. It decreases then the possibility of moisture vapour to condense to water within the structure.

A vapour retarder is a vapour resistant membrane attached to insulation materials (batt or roll) in order to resist the movement of the moisture vapour to cold surfaces where it could condense to liquid water. Vapour barriers are always installed toward the heated space, so that they are placed between the heated room and the insulation. They protect insulation from moisture produced in heating building. While most moisture enters walls either through fluid capillary action or as water vapour through air leaks, they retard moisture due to diffusion.

III.3.3.1.3. Insulation

Heat is lost from a building through the fabric envelope (roofs, walls, floor, windows, and doors) and through infiltration of cold air via any holes and gaps. The heat transmission that would normally be accomplished through natural air movement can be slowed down by insulation materials which performance is a function of the nature of the material used, the thickness and a number of other factors.

Insulation material is available in three basic types' bans as it is shown in the following table.

Table11*: Insulation types* [26]

Type	Description
Batt or blanket insulation	This type is made of mineral wool or fibreglass, and is available faced with or without a vapour barrier. It is best use for crawl spaces or unfinished walls and, can be used also in ceilings where little or no insulation is already installed.
Loose-fill insulation	This type is usually made of mineral fibre, cellulose fibre, vermiculite, or perlite. It is convenient insulation type to use in unfinished attics, especially if some insulation is already installed. On the application process, it is poured or blown into the space to be installed.
Rigid board insulation	This type is generally made of fibreglass, polystyrene, and polyurethane. It is usually attached with adhesive mastic, and is used for crawl space perimeters, concrete walls, and "exposed" beam ceilings.

There are a wide variety of insulation materials available, and each of them has different properties. Some of them trap air more effectively than others, and produce the same insulation value with less material thickness. For example, 1mm of mineral wool insulation has the same "heat resistance" (R-value) capabilities as 46mm for concrete insulation.

R-values of standards insulating materials range from 0.84 to 3.08 per cm. The table12 shows R-values of some typical insulating materials.

Table12: *Some typical insulating materials* [26]

Insulating material	R-value/cm
Mineral wool batts	1.4
Fibreglass batts	1.24–1.4
Mineral wool (Loose-fill)	1.12
Cellulose (Loose-fill)	1.24–1.48
Vermiculite (loose)	0.84-0.84
Perlite (Loose)	0.92-1.08
Polystyrene (Rigid)	1.44-2.12
Polyurethane (Rigid)	2.24-3.08

Building regulations deal with design standards or fabric heat loss and, have historically set minimum insulation levels in terms of elemental U-values. Each element of the building envelope (roof, walls, floor, windows, and doors) is assigned a maximum heat loss rate. The following tables show some elemental U-values of each element of the building envelope required by the building regulations.

Table13*: Maximum U-values in 2002 Building Regulations Part L2 (England and Wales)* [23]

Element	U-value (W/m^2K)
Pitched roof with insulation between rafters	0.2
Pitched roof with integral insulation	0.25
Pitched roof with insulation between joists	0.16
Flat roof	0.25
Walls, including basement walls	0.35
Floors, including ground and basement floors	0.25
Windows, doors and rooflights (area-weighted average), glazing in metal frames	2.2
Windows, doors and rooflights, glazing in wood/PVC frames	2.0

Table14: *Maximum U-values in 2002 Building Regulations (Scotland)* [21]

Element	A* (W/m^2K)	B* (W/m^2K)
Pitched roof with insulation between rafters	0.2	0.18
Pitched roof with insulation between joists	0.16	0.16
Flat roof	0.25	0.22
Walls, including basement walls	0.30	0.27
Floors, including ground and basement floors	0.25	0.22
Windows, doors and rooflights (area-weighted average), glazing in metal frames	2.2	2.0
Windows, doors and rooflights, glazing in wood/PVC frames	2.0	1.8

*Column A refers to a building with a heating system boiler efficiency above a certain standard.
Column B applies to all other dwellings

The target U-value method sets a requirement for the average U-value, which can be achieved trough any combination of insulation levels of individual elements and areas of windows, doors and roofights. The effect of the heating system and solar gains are also taken into account.

III.3.3.1.4. Energy efficient window and glazing systems

Energy efficient window glazing can admit the maximum light and solar gain in winter months with a minimum of heat loss. It can affect both heating and electric requirements within a building, and therefore reduce the energy use throughout the year.

One method of reducing heat gains or loss through windows is coating the glass with an invisible, heat reflective material called low-e glazing. Low-E coatings can be applied to double pane glass to minimize heat loss through window. These glazing let solar heat in to offset winter heating system requirements and keep the warmth inside. Thus, low-e coatings can reduce radiation heat transfer to the point that heat transfer by natural convection becomes dominant. However, this convection loss can also be reduced substantially by applying the technique of double glazing that creates an air space between the panes of the glass. The air space created between the panes could be filled with an inert gas (argon; krypton) to further improve thermal resistance.

Also the advantage of having an inert gas between the panes of glass is that the gas transfers less heat than air does, because it has a lower U-value and is denser than the air, so it conducts less heat. Thus a double panes window unit with argon or krypton gas loses less heat than a double panes window filled with air. The table below shows U-values of different types of low-e double glazing windows.

Table15: *U-values in W/m^2K for PVC-U or timber windows with various glazing combinations*. [22]

	Gap between panes		
Double glazing (air filled)	6mm	12mm	16mm/more
Double glazing (low-E, εn=0.2, air filled)	3.1	2.8	2.7
Double glazing (low-E, εn=0.15, air filled)	2.7	2.3	2.1
Double glazing (low-E, εn=0.1, air filled)	2.7	2.2	2.0
Double glazing (low-E, εn=0.05, air filled)	2.6	2.1	1.9
Double glazing (argon filled)	2.6	2.0	1.8
Double glazing (low-E, εn=0.2, argon filled)	2.9	2.7	2.6
Double glazing (low-E, εn=0.15, argon filled)	2.5	2.1	2.0
Double glazing (low-E, εn=0.1, argon filled)	2.3	1.9	1.8
Double glazing (low-E, εn=0.05, argon filled)	2.3	1.8	1.7

εn is the emissivity of low-E glass.

III.3.3.2. Heat gains/losses

III.3.3.2.1. Heat gains

The flow of heat through a structure is dependent not only upon the thermal properties of the structure, but also upon the heat exchanges between the surfaces and air. The manner in which heat enters a space is typically indicated as: solar radiation through fenestration; heat conduction through envelope; heat generated within the space by people, lights, electrical equipments or appliances; or any other electrical; mechanical; or thermal process within the space.

Heat gain is the rate at which heat enters or is generated within a space at a given instant. It is classified by the manner in which it enters the space and whether it is sensible or latent heat. Heat can be generated within the building by various activities and equipments that are not primary designed to give heat. The major sources of such heat are: heat from people; heat from lighting; heat from cooking and water heating; heat from machinery, refrigerators, electrical appliances; etc. For example, all electrical power entering a lighting fixture ends up as heat in the space. This heat dissipated by lighting fixtures will reduce air conditioning loads, and can be used as a source of hot air.

Heat can also enters the building through walls, floors, ceiling, windows, doors and other openings in the building fabric. The heat gained in a building by a radiation from sun depends upon various factors such as geographical latitude of the site; the orientation of the building on site; the local clouds conditions; the angles between sun and the building surfaces; and the nature of the building structure (roof, walls). The rate at, which heat from the sun falls on a surface varies throughout the day and the year. During the winter periods, the fabric solar heat gains through alls and roofs are considered negligible for masonry buildings. For heavyweight construction, little solar heat reaches the interior of the building because it delays the heat transmission until the direction of heat flow is reverse with the evening arrival.

III.3.3.2.2. Heat losses

Windows and the air infiltration are by far the largest contributors to the heat loss. However, the heat transmission through the materials of walls, roofs, and floors contributes also to the heat loss from a building. This may occurs when a wind blows across the fabric, the rate of heat transfer through the envelope increases.

Some important factors which affect the rate at which heat is lost are: insulation of building; area of the external shell; temperature difference between inside and outside the building; air change rate; exposure to climate; and the use of the building.

The greater the area of external surfaces, the greater is the rate of heat loss from the buildings. The temperature difference increases the rate of heat lost by conduction and ventilation. As the air flow from the warmer area to the colder, warm air leaving a building carries heat, and is replaced by colder air. The air flow occurs through windows; doors and gaps in construction. This air change may be accidental infiltration.

There is usually some wastage of heat energy used for water heating and space heating, and the design of the services can minimize or make use of this heat wastage.
The heat given off by the hot water storage cylinders and distribution pipes, even well-insulated ones, should be used inside the building if possible rather than wasted outside.

III.3.3.3. Ventilation systems

Ventilation in buildings is the process of changing air in enclosed space. It exchanges indoor air with outdoor air by taking continuously new air from a clean source, in order to provide comfort to the occupants.

The main objectives of ventilation systems in buildings are the following: supply of oxygen; removal of dioxide of carbon; control of humidity and air velocity for human comfort; removal for body odours, micro-organisms, moisture, heat, particles such as smoke and dust; removal of organic vapours such as cleaning solvents; removal of combustion products from heating and cooking; removal of ozone gas from photocopiers and laser printers; removal f methane gas and decay products from ground conditions.

Ventilation of a building helps to remove moist air, which might otherwise condense if it is cooled inside, and damage the building. This system is capable of limiting the moisture accumulation within a building.

In simple case, it is assumed that if air is actively extracted by a fan, then the air will flow in to replace the extracted air. So the supply rate will match the extract rate, although the source of the supply may need to be considered in the ventilation design. Ventilation process extracts, before it is generally widespread, water vapour and/or pollutants from areas where there are produced in significant quantities.

The design of ventilation systems needs to take into account of: volume of air; movement and distribution of the air; infiltration; temperature and humidity change; energy conservation; and control. The common systems used to control some or all of these factors can be considered as two broad types: natural ventilation and mechanical ventilation.

III.3.3.3.1. Natural ventilation

Natural ventilation is the traditional method that allows fresh outdoor air to replace indoor air. It is uncontrolled air movement into a building through cracks and infiltration, and through vents such as window and doors. This system operates without the use of a fan or other mechanical systems.

Natural ventilation is provided by two broad mechanisms such as air pressure differences, as caused by the wind direction or air movement over and around the building; and stacks effect caused by natural convection of warm air rising within the building. However, natural infiltration in building is unfortunately unpredictable and uncontrollable because it depends on the building’s air tightness; outdoor temperatures; wind; and other factors.

If these natural forces are not present, the building may lack sufficient ventilation for pollutants removal, it may sometimes be necessary to use mechanical ventilation.

Buildings with high infiltration rates may experience high energy costs. The high infiltration may allow contaminant air to enter from polluted areas. So, the building should be tightly sealed to reduce infiltration, and a mechanical ventilation system should be installed to provide fresh air and remove pollutants when and where needed, in a controlled manner that does not negatively impact indoor air quality, or heating and cooling bills.

III.3.3.3.2. Mechanical ventilation

Buildings need to have an indoor/outdoor exchange of air to replenish oxygen used by the occupants and to remove pollutants generated by breathing, different activities within the building and emissions from building materials and furnishings. The decision to use mechanical ventilation systems is typically motivated by concern that natural ventilation is not providing adequate air quality. The use of mechanical ventilation makes it possible to use spaces such as deep within the buildings that could not be easily ventilated by natural means.

Mechanical ventilation uses a fan or fans to create air change and movement. Unlike natural ventilation, the system can be designed to provide a positive air change and air movement. However, it costs more to install, operate and to maintain. There is also a risk of noise from fans and ducts. A significant part of the operating cost associated with a ventilation system is the electricity used to operate a fan. Energy efficient fans should be used to reduce these costs. Fans selected for ventilation systems should be manufactured for continuous operation and long life, and installed in location that is easily accessible for regular maintenance.

Mechanical ventilation systems are also used to control interior pressure, with respect to outside, to maximize the building durability, combustion safety and indoor air quality. Since this system has costs associated with it such as the costs of electricity to run it, and the cost of heating the outdoor air that the system brings in, mechanical ventilation system must operate only when needed, and would do so automatically without the need for occupant intervention. The costs of heating the outdoor air that the system brings in can be reduced by incorporating heat recovery capabilities in the system.

There are three main types of mechanical ventilation such as exhaust ventilation which forces inside air into the building; supply ventilation which forces outside air into the building; and balanced ventilation which forces equal quantities of air into and out of the building.

Exhaust ventilation systems works by reducing the inside air pressure below the outdoor air pressure. They extract indoor air from the building while make up air infiltrates through leaks in the building shell, and through intentional passive vents.

The supply ventilation systems works by pressurizing the building. By pressurizing the building, they discourage the entry of pollutants from outside, and allow outdoor air introduced into the building to be filtered, to remove pollen and dust. In winter, they cause warm air interior to leak through random openings in the exterior wall and ceiling. If the interior air is humid enough, some moisture may condense in the attic or cold outer parts of the exterior walls where it can promote mould, mildew, and decay. So, this system has the potential to cause moisture problems in cold climates.

Balanced ventilation systems neither pressurize nor depressurize a building, if properly designed and installed. Rather they introduce and exhaust approximately equal quantities of fresh outside air and polluted inside air, respectively. They are appropriates for all climates.

PART II: LAING O’Rourke Group: Case study

IV. LAING O’Rourke Group

IV.1.The Company’s background

LAING O’Rourke is an international construction industry, specialising in the design, procurement and delivery of major construction projects across a wide spectrum of global markets. It has currently a total of 16000 employees around the world and 9000 in the UK.

In Scotland, the business unit within this company is called Laing O’Rourke Scotland Ltd (LORS), this unit focus on construction activities, and its annual turn over is of £100m, covering a wide range of construction projects.

In this study, our aims are limited to determine the total energy use by LORS on one of its construction sites (National Air Traffic Service) especially on lighting and heating systems. And therefore, quantifying the total energy costs savings at NATS (National Air Traffic Services) construction site.

The case study was chosen due to identified problems associated with energy usage within NATS cabin accommodations. For example, despite Action Energy posters awareness, lights and heaters were generally left switched on, and windows often left open in some rooms which are unoccupied for significant periods of the day. There were also a lack of automatic control of heating and lighting which results in significant energy wastage on site. [17]

IV.2.The National Air Traffic Service Centre (NATS): Prestwick Airport

Laing O'Rourke is the main contractor on the construction of the new NATS centre, which is located next to the existing NATS building near Prestwick Airport. The construction contract started in November 2004, and is to be completed by October 2006.

At the NATS construction site, there are two types of cabin accommodation: old cabin and the new cabin accommodations. Each of them comprises a lower and an upper floor with offices; kitchens; canteens; drying rooms for subcontractors' clothes; shower rooms and toilets. The site operates 10hours a day from Monday to Friday, and uses 140 fluorescent lamps for lighting systems.

Figure5: *NATS cabin accommodations*

IV.3. NATS cabins description and structure

IV.3.1. Description

The two types of cabin accommodations located at Prestwick Airport are shown in the figure5. The old cabins are located on left side towards the north; and the new cabins are located on the right side towards the south.

For the old cabins, the windows sizes are 108cm wide by 82cm high each. These old cabins have: north-facing windows (6 windows on lower floor and 6 windows on upper floor); west-facing windows (one on lower floor and 3 windows on upper floor); and East-facing windows (2 windows on lower floor and 3 windows on upper floor).

The new cabins are also shown on the same figure, and their windows sizes are 80cm high by 69cm wide each. These windows are: East-facing (with 17windows on upper floor and 16 windows on lower floor); and West-facing (with 18 windows on upper floor and 18 windows on lower floor).

Both the old cabins and new cabins have doors of the same sizes (193cm high by 82cm wide), and the whole building has a corridor on both lower and upper floors with approximately 90cm wide and 36m long running through the centre of the cabins.

IV.3.2. Structure

As stated previously, Laing O'Rourke is the main contractor on the third phase of construction which includes cladding; roofing; building services and internal fittings with completion scheduled for October 2006. As this company doesn't have yet its own construction equipment on site, it hired cabin accommodations which are occupied by around 40 office staff and management.

The external wall has a thermal transmittance (U-value) of $0.35W/m^2K$, and is insulated with 80cm mineral fibre quilt fitted in between vertical timber studding. Its general finishes are composed by bark textured paint on plywood, and a vapour barrier is fitted directly onto internal side of the wall studs. The internal lining is made with 12.7mm cream/magnolia vinyl plasterboard fixed onto timber studding.

The floor insulation is composed by two layers of “floortherm” foil insulation over draped over joists, and bagged to create minimum 25 air void between layers and the underside of timber deck. The floor has a thermal transmittance (U-value) of 0.25W/m^{2}K). The floor deck is made with 18mm WBP plywood glued and nailed to floor joists. The flat roof structure has a thermal transmittance (U-value) of 0.25W/m^{2}K), and its insulation is composed by 80mm expanded polystyrene fixed between joists with a layer of 80mm fibre glass insulation quilt above, between the firings, plus. One layer of floortherm foil insulation and vapour barrier are laid at the ceiling level. The internal lining is composed by 12.7mm white vinyl plasterboard fixed into ceiling joists.

External doors are covered with laminated glass, paint finish and have 838mm internal blonde oak door. Windows are double glazed, and have a thermal transmittance of 2.75W/m^{2}K.

V. ESP-r modelling and methodology

The modelling was made in order to identify the effect of some design change such as increasing wall insulation, changing glazing type, introducing daylight control devices, and changing the heating control regime. And to determine the benefits that can be expected from energy efficient strategies.

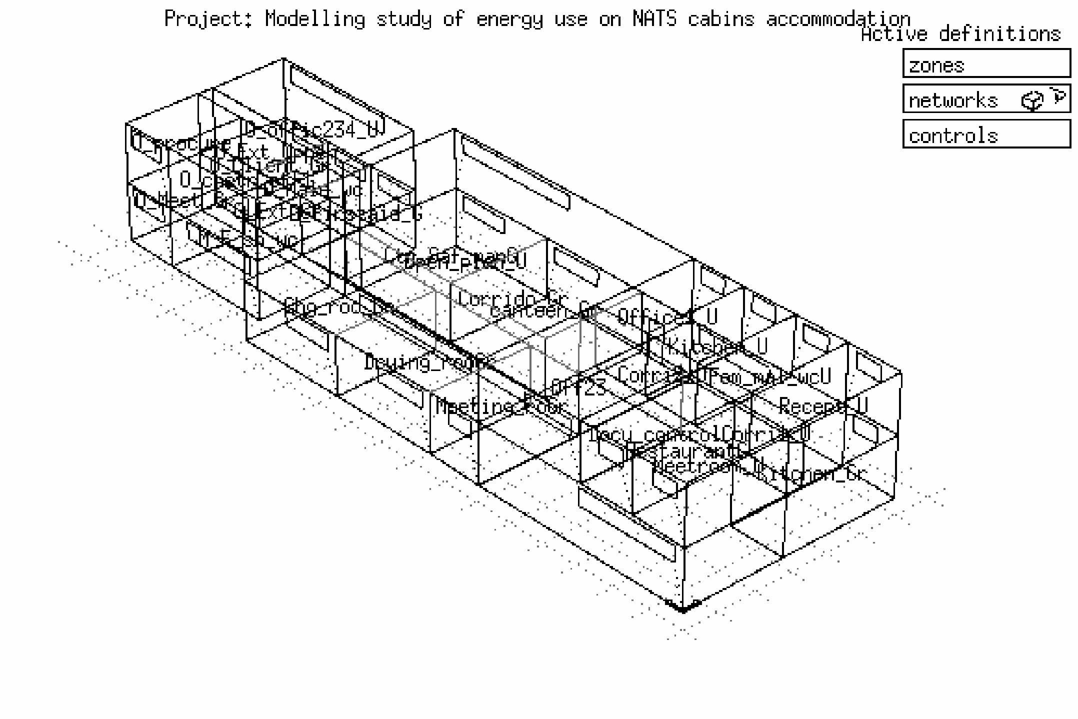
V.1. Methodology

V.1.1. Geometry

To make the model less complex and more understandable, the number of zones was reduced to a minimum by combining: some windows for the same zone and the same side; and the zones with the same occupancy level, within it the same activities were undertaken on the same periods. These zones were also created according to the volume and associated usage of each zone.

By using the above logic, NATS cabins were divided into 28 zones which in reality represent the old cabin and new cabin accommodations. The following figure (figure6) shows the geometry of the two types of NATS cabin.

Figure6: Geometry of the old cabin and new cabin accommodations of NATS



V.1.2. Constructions

With the aid of some pre-existing databases which contain construction profiles, physical properties and surface boundaries were attributed to the zones. The composition of surfaces; the type of surface (opaque or transparent); and the environment conditions were defined. Also, the construction layers were defined from the outside to inside order. Each zone was attributed a specific name which facilitates its recognition. As it is shown in the table below:

Table16: *NATS construction zones and their sizes*

Zones	Volume (m^3)	Base/Floor area (m^2)	Opaque construction (m^2)	Transparent Construction (m^2)
1. Restaurant_	374	125	386	7.73
2. Kitchen_	58.1	19.3	94.3	1.10
3. Meeting_	50.	33.3	83.5	1.10
4. Drying_	99.9	66.6	134	2.21
5. Changing_	99.9	66.6	134	2.21
6. Corridor_	90.5	60.3	189	0.000
7. Canteen_	99.9	66.6	134	2.21
8. Cnst&saf_	99.9	66.6	134	2.21
9. Meeting-U	50.	33.3	83.5	1.10
10. Doc_contr	50.	33.3	83.5	1.10
11. Off23_U	99.9	66.6	134	2.21
12. Corri-1U	8.10	5.40	28.8	0.000
13. Corri_2U	24.3	25.2	75.6	0.000
14. Recept_U	50.	33.3	83.5	1.10
15. Fe_mal_U	50.	33.3	83.5	1.10
16. Kitchen_U	50.	33.3	83.5	1.10
17. Offic1_U	50.	33.3	83.5	1.10
18. Open_plan	540.	327.	511.	11.0
19. O_Ext_gr	27.	36.	83.4	0.000
20. M_F_shwc	72.9	24.3	105	3.54
21. O_meet_gr	36.5	24.3	64.8	1.77
22. O_firstAid	36.5	24.3	64.8	1.77
23. O_male.wc	36.5	24.3	64.8	1.77
24. O_client_g	36.5	24.3	64.8	1.77
25. O_off234	109.	72.9	146	5.31
26. O_ExtUpp	27.	36.	83.4	0.000
27. O_cntrOff1	72.9	48.6	107.	1.77
28. O_procu_	36.5	24.3	68	1.77

V.1.3. Internal gains and schedules

On NATS construction site, cabins are occupied from Monday to Friday (8h to 18h); lights are on and off during this period and some electrical devices are used on this period. In order to define the essential characteristics of what goes on in cabins, casual sensible and latent heat gains for people; lights and small power has been considered, this provides schedules for the different casual gains on Weekdays; Saturdays and Sundays.

This model was run for 40 persons working on site on weekday period from 8h00 till 18h00, and it is assumed that one person doing the office work produces 90W sensible and 45W latent heat gain.

V.1.4. Ventilation

The air flows; infiltration and/or ventilation rates have been defined on basis of air changes per hour. This latter vary with the occupancy level and the activity undertaken within cabins.

For the reasons of indoor air quality, it is recommended that the fresh air supply shouldn't be less than 0.5ac/h even if there is no one in the room. So, in this model, we considered a permanent infiltration of 0.5ac/h when the cabins are not occupied (night times; and weekends). During the weekdays, the infiltration rate could be high (more than 0.5ac/h) due to the doors and windows opening; and the number of occupants.

V.1.5. Heating control

In NATS cabin accommodations, the inside environmental temperature is controlled and maintained at 21°C for cabin offices; at 19°C for corridors and 18°C for showers and toilets.

For the heating control, 4 control loops were created and therefore connected to the 28 zones of the model. This is to sense the temperature in each zone and to define a control strategy for periods and temperature set points.

For each day type, control periods were defined (3 control periods for weekdays: 0h00; 8h00; and 18h00, and one control period on weekends). These day types and periods allow the control to be switched off during the weekend days and the nights on weekdays. On working time however, the control is activated when the inside air temperature drops below or exceeds the heating set point. As no cooling required on this model, the cooling set point is 100°C which is an impracticable temperature. So, with this value, no zone humidity control required

V.2. Simulation strategies

In this study, simulations were run for both winter and summer periods, and only one week was selected for each period in order to take into account of the construction heat storage. For the winter period, the typical week chosen was: Tuesday 14Feb 06 @00h30 to Monday 20Feb 06 @23h30; and for summer period, the typical week selected was: Tuesday 15Aug 06 @00h30 to Monday 21Aug 06 @23h30. These weeks are important because they give a real image of the average temperature conditions for each period (winter or summer).

As said previously, our aim is to analyse the total energy delivered at NATS cabin accommodations; the zone flux transfer (gains/losses) on the cabins surfaces to see the effect of some design change; and the casual gains (occupant heat gains; lights heat gains and small power heat gains).

VI. Results analysis

VI.1. Infiltration air load within NATS cabins

In summer periods, most of the 28 zones defined previously, can use natural ventilation, and the opening and closing of doors and windows are manually sufficient to provide the required fresh air.

The openings are the main means of removing the excess and unwanted heat gains, as well as the removing of body odours. This is made according to the internal temperatures.

It is recommended that in absence of further information 8 l/sec/person should be taken as the minimum ventilation to control body odour levels in rooms with sedentary occupants. In this study, the control of ventilation systems is based to the occupancy variation, and to the sources of contaminants. And we considered that some controls over the air flow rate are achieved by opening or shutting windows.

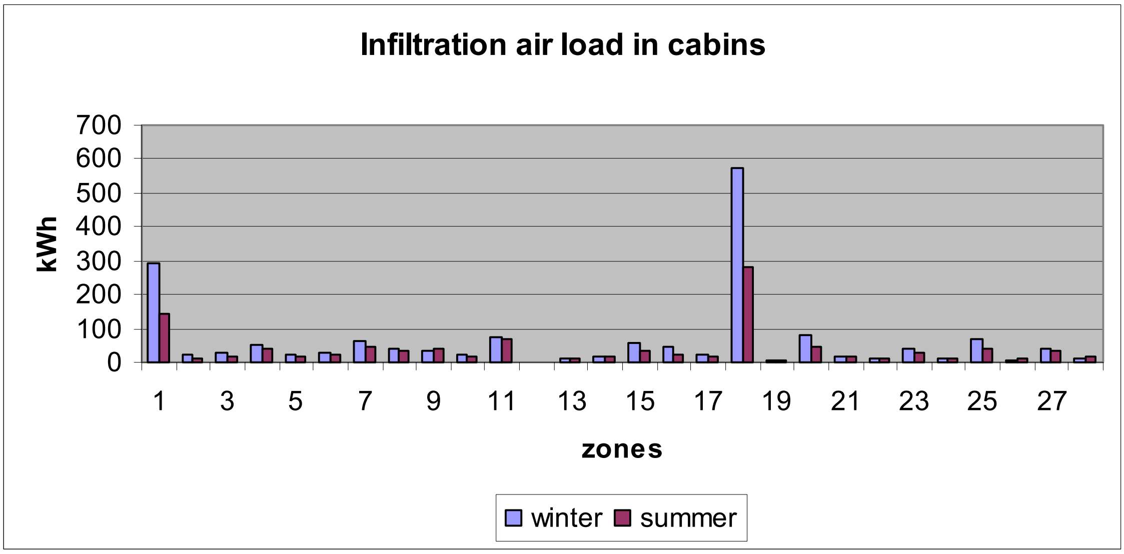
During a large part of the year, the temperature of the outside air is less than that for the inside of the cabins. Therefore, the cooling is associated with the air infiltration, and the conduction part of the load due to windows is negative.

In winter periods for example, winds blow cold outdoor air into indoor spaces through cracks around windows and doors on windward side of the cabins. Consequently, the rate of air infiltration increases depending on the difference between the temperatures inside and outside the cabins. Added to this, the total volume of the air passing through the cabins structure in winter is much greater than that for summer periods due to inside and outside temperature difference. Heat is therefore lost through the building structure, and air infiltration causes a net heat loss more in winter than in summer.

The infiltration air load varies depending on the internal and the external air temperature difference; and whether windows and doors are open or shut; the amount of heat stored in the structure; and the area of external surfaces.

As appeared on the figure below, the greater the area of the external surfaces, the greater is the air infiltration load. For example, the infiltration air loads for the zone1 (RestaurantG) or zone18 (Open_plan_U) is much greater than that for any manager office (office1_U for example). This is explained by the fact that some of important factors which affect the rate at which heat is lost include exposure to climate. As the air flow from warmer area to the colder, the rate of heat loss from the building depends also on the size of the surfaces exposed to the outside cold air.

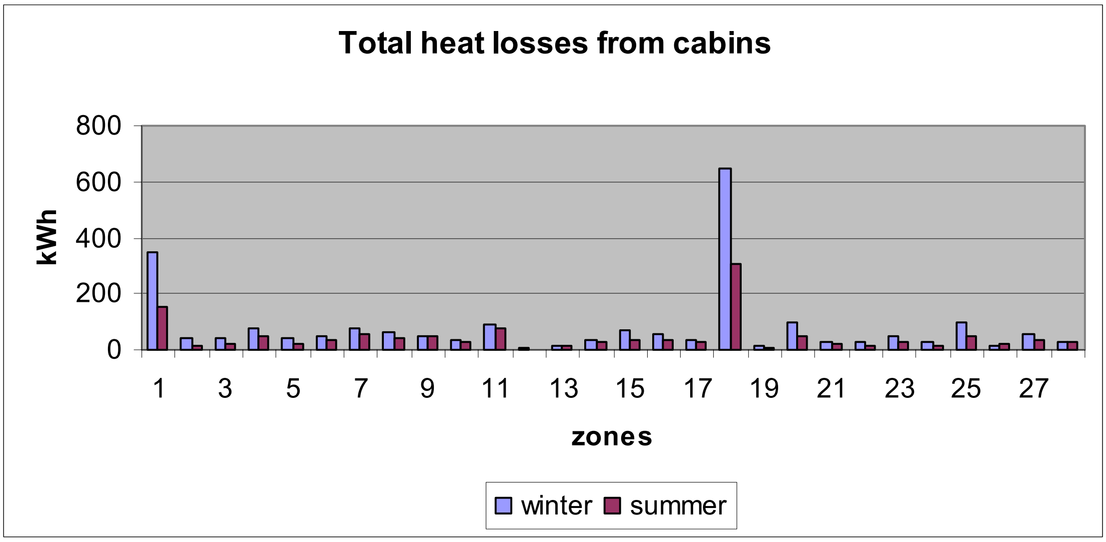
Figure7: *Comparison of the infiltration air load for a typical week in winter with that for a typical week in summer periods.*



The figure8 shows fairly winter and summer conditions within NATS cabin accommodations. The total heat losses depend upon both the area of external surfaces, and the periods of the year.

On this figure8, it appears that the total heat loss is higher in winter periods than in summer periods for the same zone. This result is to be expected because the total volume of air passing through the cabins structure in winter is much greater than that passing through the fabric envelope in summer periods. Heat is therefore lost through NATS cabins structure, and air infiltration causes a net heat loss more in winter than in summer.

Figure8: *Comparison of heat losses for a typical week in winter with that for a typical week in summer periods.*



VI.2. Casual heat gains for National Air Traffic Service (NATS) cabins

In this case, casual heat gains take into account of the heat given off within the NATS cabins, by various activities and equipment that are not primarily designed to give heat. The major source of such heat are: heat from people; heat from lighting and other heat dissipating equipment such as computers, water heating, cookers, refrigerators, electrical appliances, etc.

Heat casual gains are additional heat loads which have a strong potential for reducing energy demand if it is used effectively. In winter for example, this heat can be used to advantage if it is distributed effectively where it is needed.

Another way to save energy from casual heat gains, is to turn equipment on and off in accordance with occupancy schedules.

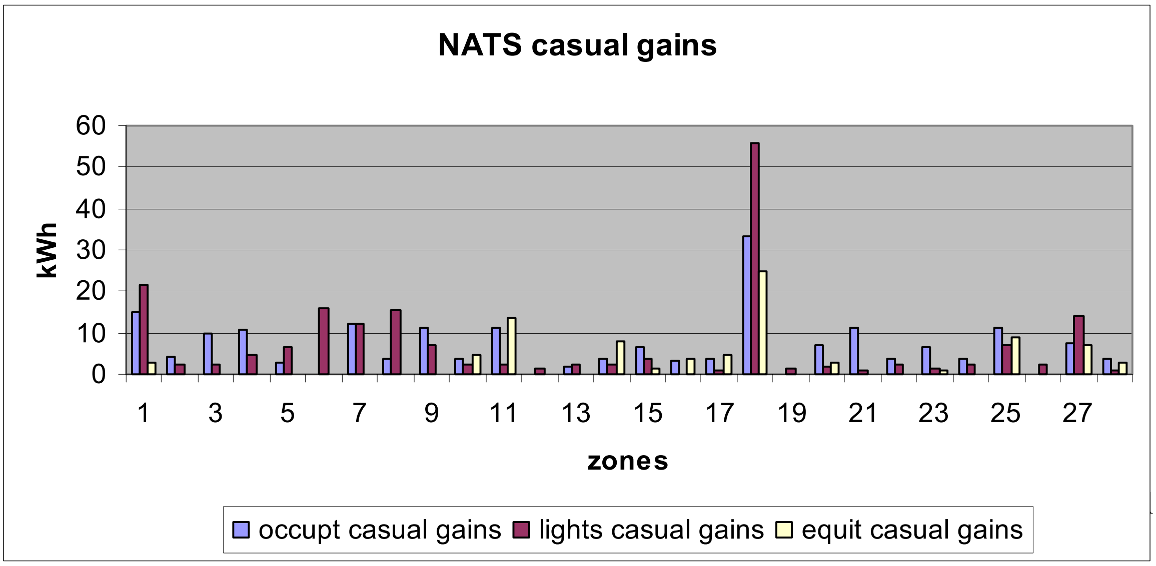
In summer, heat casual gain is another component of heat that must be removed. This is because the potential for solar heat gains may be high in summer, and this situation will have an impact on occupant thermal comfort for some zones that experience high casual gains.

Casual internal heat gains from lights; people and small equipment may contribute to summer time overheating, and the potential heat output from casual heat gains is very large inside NATS cabins, if we consider the present case.

Where the greatest emission of casual heat gains occurs, special care must be taken to reduce casual heat gains and provide controllable ventilation. For example, extra fans are used in smokers' canteen; drying room; and changing room for NATS cabins, and it may be even necessary to install balanced mechanical systems locally to remove heat, and to limit excessive casual gains. The system would only operate when the zone temperature exceed the set point temperature and would only run for a preset period.

For NATS cabins, the main determinants of heat gains from lights and appliances are the actions and choices of subcontractors themselves. Their use of equipment and appliances, and the way they use the cabins determine the magnitude and timing of the casual heat gains. However, there may be some scope for Laing'O Rourke Scotland to influence the impact of these actions.
For example, install high efficiency light; provide efficient appliances and limit their number and their size. High efficiency lighting can play an important part in the reduction of casual gains.

Figure9: *Heat casual gains sources and conditions within NATS cabins*



As stated previously, heat casual gains depend on the occupancy levels; and the use of lighting and small equipment within cabin accommodations. For example, as it appears on the above figure that 20 people using an open plan zone during weekdays produce more heat than 2 people working in a small office. Further to this, in the open plan, more lighting and small equipment are required than in small office. Therefore, more lights casual gains and small equipment casual gains are produced within NATS cabins.
As seen on the figure9, most heat casual gains are generated from lighting system.

If high levels of electric lighting are provided, it is often necessary to extract air through the lighting fittings so that the heat from them is removed and does not escape into the room. So, reducing the casual gains from lights and appliances will reduce the overheating in the areas where they are concentrated.

VI.3. Heat gains/losses through building fabric of NATS cabins

In summer periods, when the external air temperature is higher than the internal air temperature, windows opening will further increase the heat gains rather than remove heat. The fabric transmission losses will reverse and heat gains through fabric will become possible.

From, 15 /08/06 to 21/08/06 the total heat gains through the opaque walls of NATS cabins is 440.6kWh, while the total heat losses through the same opaque walls is 144.2kWh. If the thermal mass of the fabric envelope is at a lower temperature than the incoming air, it will absorb heat from both internal gains and the incoming ventilation air. The heat absorbed will then be released to the outside area when the external air temperature becomes lower than that for the thermal mass temperature (at night times for example).

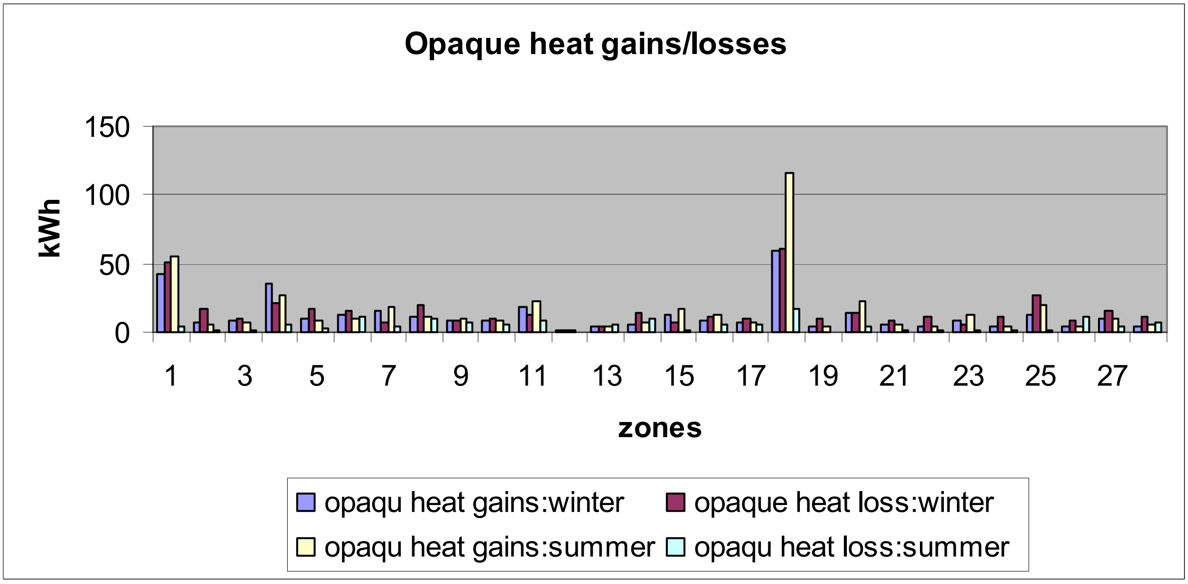
On the typical week considered in summer, the cooling system which could be done only by opening windows and doors is required for redressing the balance between heat gains and heat losses.

From 14/02/06 to 20/02/06 the total heat losses through opaque walls of NATS cabins is 417.6kWh, while the total heat gains through the opaque walls of the cabins is 349.4kWh on the same period. It shows that, in winter periods the heating system is required for heat gains and heat losses balance.

Figure10 shows that heat loss through opaque walls of each of the 28 zones for the model is much greater in winter periods than it is in summer periods. However, heat gains through opaque walls of each of the 28 zones, is lower in winter periods than it is in summer periods.

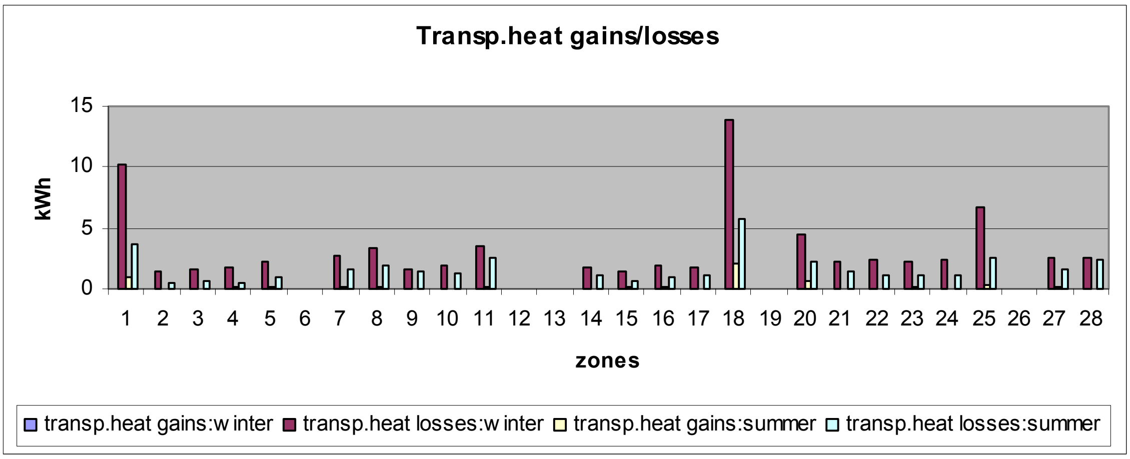
In summer periods, heat losses through opaque walls for each of the 28 zones, is lower than heat gains through the same building fabric. However, in winter periods, heat losses through opaque walls for each of the 28 zones are higher than heat gains through the same fabric.

Figure10: *Total heat gains/losses through NATS opaque structure*



The figure10 shows that heat gains in summer periods is high than it is in winter periods. This may results to the potential for solar heat gains which is important in summer, and very low in winter. It also appears on the above figure that heat loss through opaque structure is higher in winter than in summer periods due to the inside and the outside temperature difference.

Figure11: *Transparent heat gains/losses for NATS cabins*



As it appears on the figure11, the transparent heat gains/losses depend not only on the type of the transparent material, but also on its size. For example zone1 (RestaurantG), and zone 18 (Open_plan_U) are where transparent heat gains/losses are higher than other zones for NATS cabins. In zones 12 and 13, there is no transparent gains/losses because these are corridors, and they have no transparent areas.

In winter periods, transparent heat gains are lower than they are in summer periods. However, the opposite appears for transparent heat losses for both seasons. This may results on solar heat gains that are more important in summer than in winter periods.

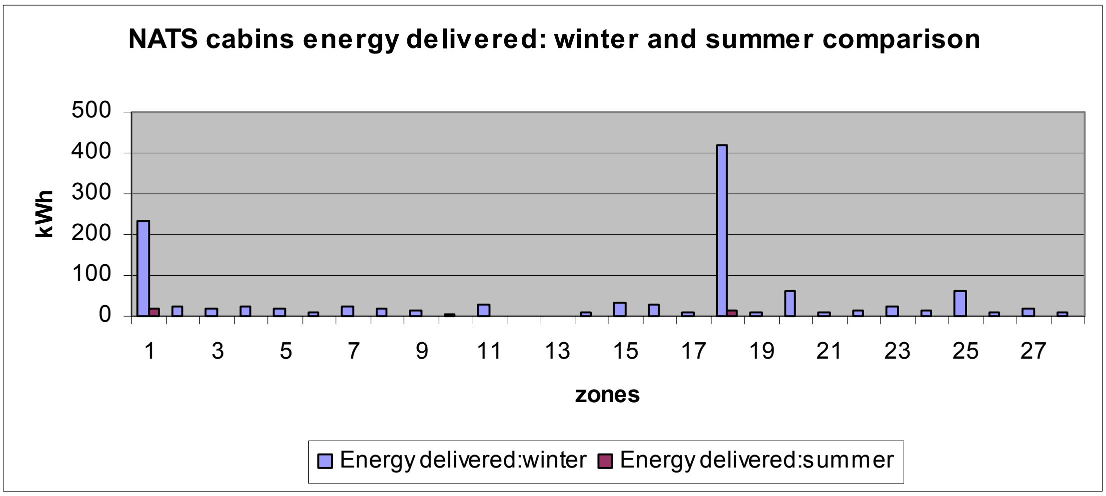
VI.4. Heating requirements for NATS cabin accommodations

The energy requirement within cabins at any particular time depends on the state of heat losses and heat gains at that time. To maintain the required indoor conditions, heat casual gains given off by lighting; people; and small equipment, make an important contribution to the energy conservation and to the sizing of heating equipment. It can be used for space heating rather than to be wasted to the outside, and the energy delivered by a heating device could be reduced and therefore saving energy.

When casual heat gains and solar heat gains are used efficiently for space heating, the size of the heating equipment and the external heat source can be reduced to maintain proper temperature within the building. Then, an analysis of internal loads and comfort temperatures is needed; and appropriate scheduling of equipment operation during each season of the year can help to keep energy requirement to a minimum level.

When the outdoor air temperature drops significantly (in winter for example), there is a large difference between inside and outside temperatures of cabins which increases the rates of heat losses by conduction and ventilation. Therefore, the internal heat gains may be insufficient to meet the space conditioning requirements. As the heat losses are greater than heat gains, a certain level of heating is required for balancing losses and gains inside the building.

Figure12: *Total energy required for space heating within NATS cabin (for a typical week)*



The figure12 shows the total energy to be supplied by a heating system within NATS cabin accommodations. In summer, casual and solar heat gains are sufficient to meet the heating requirements. However, in winter period the more heat is lost, the more energy demand increases for maintaining the temperature comfort inside the cabin.

VI.5 Thermal insulation and double glazing

VI.5.1. Introduction

In this part of the thesis, design changes options such as insulation and glazing types were modelled in order to see their technical performance in term of energy usage and identify the right alternative methods to save energy. Different U-values for insulated external wall and double glazing window were used in the model, and these parameters were chosen because they may affect the total energy consumption. For example window glazing can be used to affect heating requirements and occupants comfort by controlling the type and the amount of light that passes through windows. And well insulated external wall has the benefits to improve the thermal performance of the building.

Insulation and glazing materials are well qualified to lower heat loss and gain; they make an important contribution to energy conservation and to the sizing of heating equipment. They also offer practical means for reducing heating loads without affecting the basic system design, or without making demands to the users to change their living patterns.

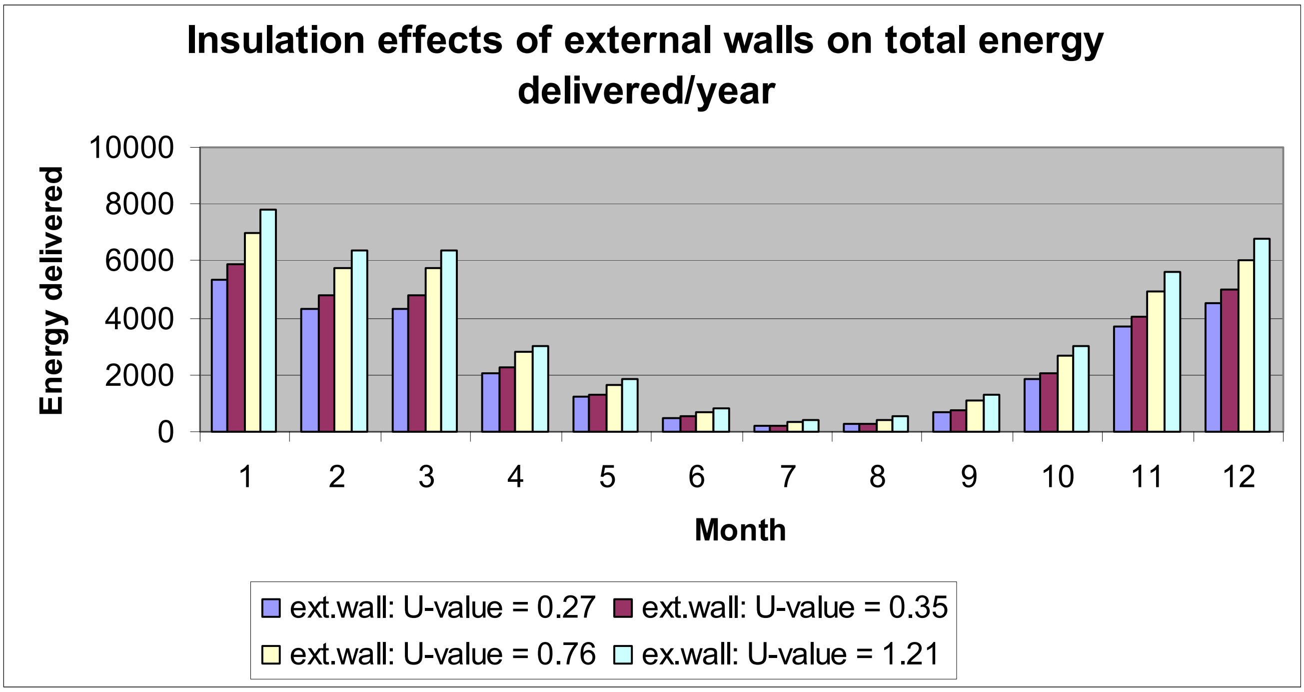
The best way of reducing the internal surface temperature of windows and walls, and therefore increase the dry bulb temperature is to combine improved insulation of walls and windows with reduced surface emissivity.

VI.5.2. Insulation materials

The aim of an insulation material is to reduce heat transfer, so it is worthwhile to examine the performance of different insulation materials to see whether the applications might pay dividends. In fact, the amount of insulation that should be applied to a surface is usually based on an economic trade-off between savings and insulation costs.

One option for reducing the amount of energy consumed in warming a space is to increase the thermal resistance of the building envelope. This is done by increasing insulation levels of the structure, and therefore heat can not escape easily from an interior zone to the exterior zone.

Figure13: *Effects of insulating external walls on total energy consumed within NATS cabins*



In figure13, it is assumed that NATS cabins have double glazing windows with a constant U-value of 2.75W/m^{2}K. So, on this case, we are evaluating the impact of external walls insulation on the total energy delivered at NATS cabin accommodations.

By insulating the external walls, their coefficients of transmittance (U-values) decrease or increase depending on the type of insulation, or the insulation level of the structure. Then, energy delivered can vary with the variation of the U-value of external walls depending to the type of insulation materials installed. This is shown in the table below:

Table17: *Energy delivered if the U-value of double glazing window is 2.75 W/m^{2}K.*

External-wall: U-value (W/m^{2}k)	Window Double glazing U-value: (W/m^{2}k)	Total energy delivered (kWh)/year
0.27	2.75	29009.66
0.35		31864.65
0.76		39079.65
1.21		43846.4

Due to the insulation materials that tend to delay or stop heat transmission, the coefficient of transmittance (U-value) decreases, and therefore the total energy consumed decreases.

As it is shown on the table17, the greater the U-value of external wall the greater the total energy is delivered. Also, a minimal level of heating is required in cabins insulated to current regulation standards. The maximum allowable elemental U-values for external walls are: 0.35W/m^{2}K (in England and Wales); and 0.30 or 0.27W/m^{2}K (in Scotland).

Scottish regulations in 2002 required lower elemental U-values for external walls than the equivalent regulations in England and Wales. This because technical standards required in Scotland are different to those using a system of approved documents in England and Wales. The revised 2002 England and Wales regulations have tried to simplify the situation. Rather than having a separate method, the elemental method now includes a higher degree of flexibility.

The external insulation is more effective because it eliminates thermal bridges; reduces air, wind and moisture penetration through the building envelope, and therefore keep the whole structure warm. As the coefficient of transmission of external walls increases, the heat loss from the building increases, and therefore the total energy consumption increase as well. In this case, if we compare the total energy delivered from the highest U-value, with that from the lowest U-value, the total energy which could be saved/year by changing only the U-value of external-wall is 14836.74 kWh.

It is also important to recognise that increased thermal insulation reduce both the carbon dioxide emissions and the total energy consumption.

VI.5.3.Double glazing window

Windows and the infiltration rate are by far the largest contributors to heat loss. Further considerations should be given to the energy efficient windows; to improving seals around the windows; or to reducing their size.

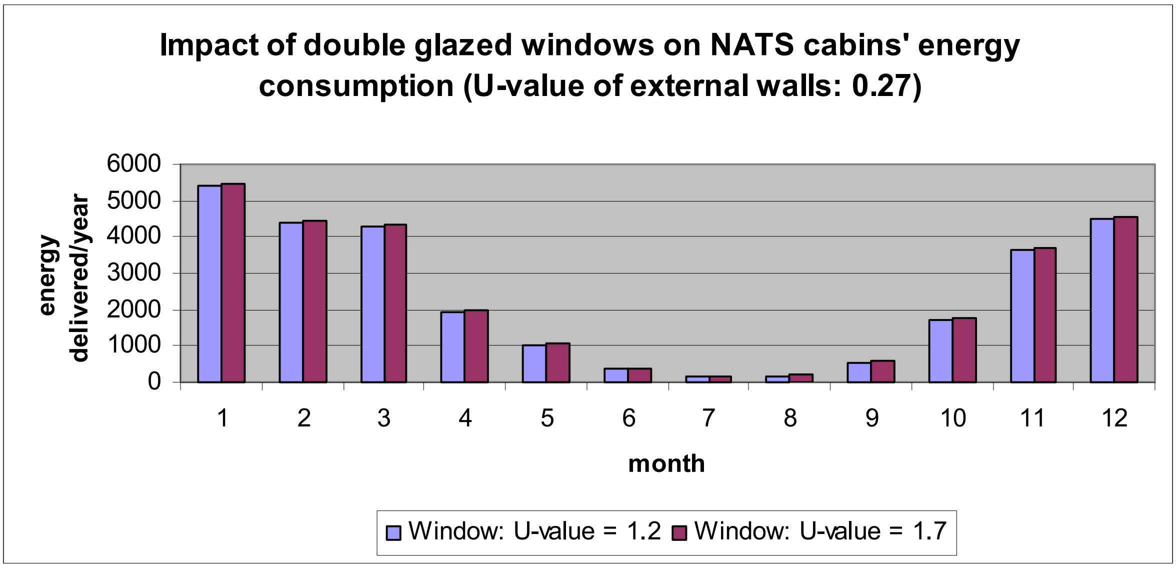
Energy efficient windows are designed to keep heat inside the building in winter and outside the building in summer. This reduces heating costs; minimizes energy consumption; and limits the size of heating equipment required for keeping the building comfortable.

One common method of reducing heat gain or heat loss through windows is by coating the glass with an invisible heat reflective material. Low-e coating can reduce radiation heat transfer, and further heat reduction can also be substantially done by filling the air space between panes with a high-molecular weight gas like argon or krypton. Once the thermal resistance of a unit has been improved with a low-e coating and an inert gas, newly developed spacers can considerably reduce heat loss.

A low-e coating can reduce the U-value of a double glazed window. This latter, indicates the rate of the heat flow due to conduction and radiation through a window as a result of a temperature difference between inside and the outside.

In figure14, it is assumed that the external walls of NATS cabin accommodations have a constant U-value of 0.27W/m^{2}K. And the effects of glazing systems and their modifications on the total energy delivered at NATS cabin accommodations are examined

Figure14*: Effects of glazing systems and their modifications on total energy consumed (with U-value* of *with external wall:* 0.27W/m^{2}K)



As it appears in figure14, the energy loss through low-e double glazing windows is reduced because the energy leaving the cabins through windows is less than energy coming into the cabins through windows.

And on the tables (18 an 19), the results show that the lower the U-value of double glazing window, the lower the heat loss, and therefore the less heating is required.

Table18: *Total energy delivered if the U-value of external wall is 0.27 W/m^{2}K*

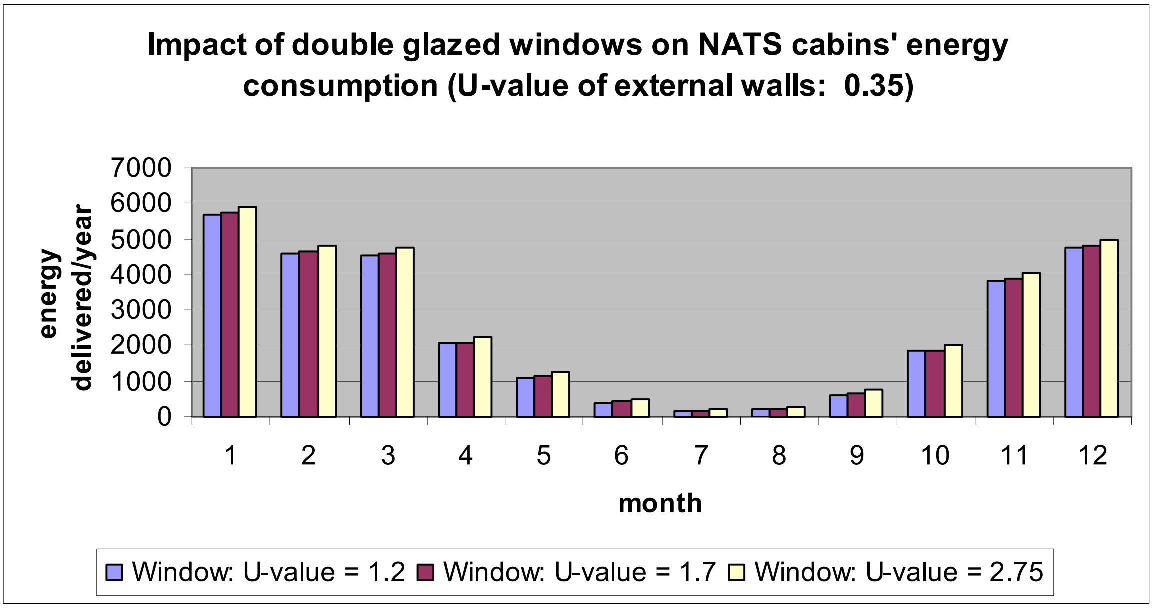
Window double glazing: U-value (W/m^{2}K)	External-wall: U-value (W/m^{2}K)	Total energy Delivered per year (kWh)
1.2	0.27	28101.48
2.75		29009.66

Table19: *Total energy delivered if the U-value of external wall is 0.35W/m^{2}K*

Window double glazing: U-value (W/m^{2}K)	External-wall: U-value (W/m^{2}K)	Total energy Delivered per year (kWh)
1.2	0.35	29704.18
1.7		30187.18
2.75		31864.65

High performance energy efficient windows have an impact on total energy consumption. They have lower heat loss and less air leakage, and can improve comfort and minimize condensation. On this study, if we compare from the above 2 tables (18 and 19) the highest U-value with the lowest U-value, we could find the total energy which could be saved/year by only changing the U-value of double glazing windows. This latter is 2160.47kWh (i.e. small effect compared to changing wall U-value).
The following figure shows the impact of glazing systems on the total energy delivered.

Figure15*: Effects of glazing systems and their modifications on total energy consumed (with U-value* of *with external wall:* 0.35W/m^{2}K)



Replacing non efficient glazing with advanced insulating glazing leads to the energy savings and consequently, to the CO_2 emissions reduction.

VI.6. Impact of windows and doors opening on total energy delivered

Windows can represent a major source of unwanted heat loss and discomfort if they are left open unnecessarily. In winter for example, wind blows a large volume of outdoor cold air, into indoor spaces through the opening paths. And the energy required for heating indoor spaces is associated with air infiltration. If the air infiltration rate increases, the total energy delivered increase as well.

Windows are often left opened on NATS cabins, even when there are unoccupied for significant periods of the days. In this situation, it is obvious that the air infiltration becomes very high because the opening windows produce a boost in ventilation rate. The increases of air infiltration within cabins have significant effects on total energy consumption as it is shown in the table below.

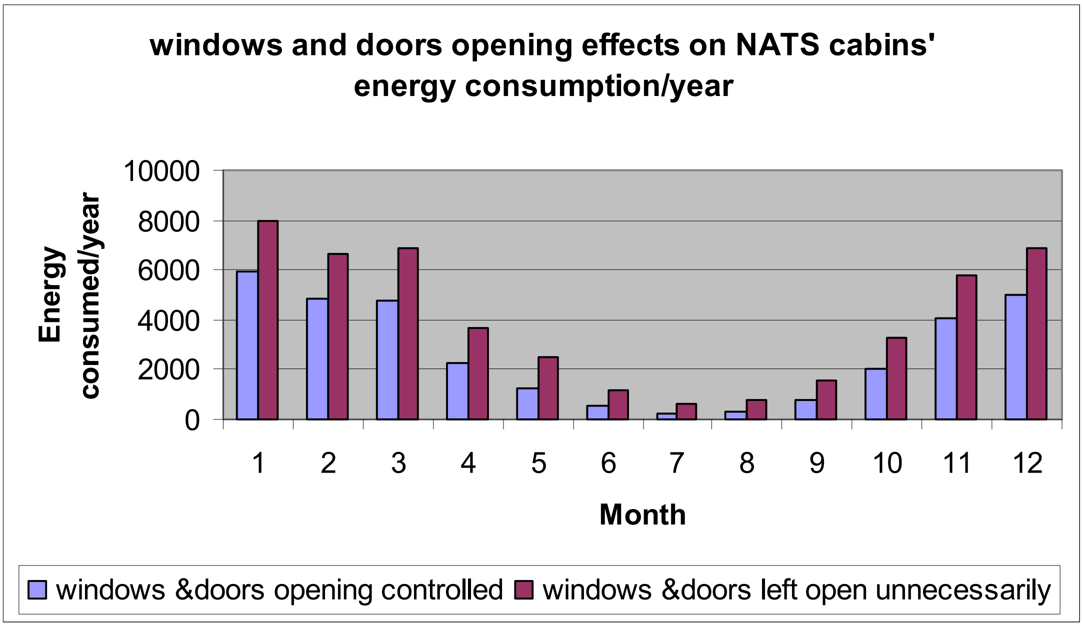
Table20: *Impact of air changes variation on total energy delivered at NATS cabins*

Double glazing window: U-value (W/m^2K)	External wall: U-value (W/m^2K)	Minimum air changes rate (ac/h)	Total energy delivered (kWh)
2.75	0.35	0.5	31864.65
		1.5	47846.67
	0.76	0.5	39079.25
		1.5	52907.71
	0.67	1.5	51820.52
		2	60327.85

From the above table we can see that, the total energy delivered in NATS cabins is affected by the variation of air infiltration rate. If the infiltration rate increases, the total energy consumption will increase as well. For example in the above table, the U–value of double glazing window is taken to be 2.75W/m^{2}K, and that for external wall to be 0.35W/m^{2}K, and the ventilation is kept to a minimum when cabins are not occupied because it can not be eliminated completely. If the air change rate is kept to a minimum of 0.5ac/h on one hand, and to 1.5ac/h on the other hand, the difference of total energy consumed within cabins is 15982.02kWh. This result reflects the impact air infiltration that has on the heating requirement.

Figure16 shows the effect of the increased infiltration rate on total energy consumption/year: (external-wall: U-value = 0.35W/m^{2}K; and double glazing windows: U-value = 2.75W/m^{2}K).

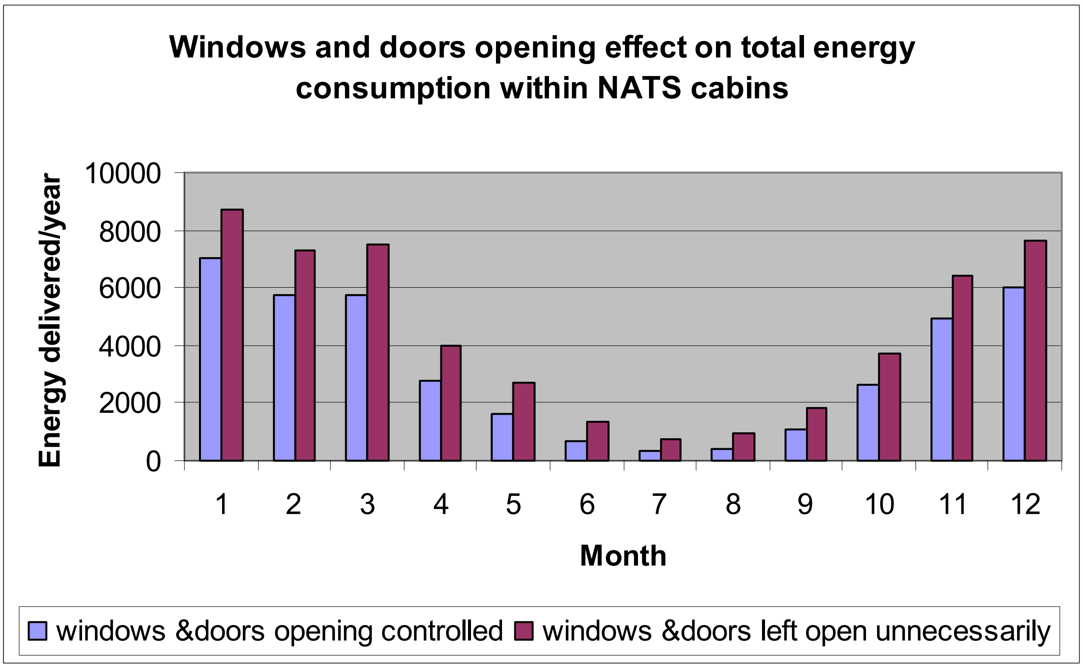
Figure16: *Impacts of increasing infiltration rates on the total energy delivered/year (U-value for ext.wall=0.35W/m^{2}K; U-value for double glazing window=2.75W/m^{2}K)*



On NATS cabins windows were often left opened unnecessarily. This situation leads to the energy wastage. In this study it is assumed that, if the opening occurs for most of the time, the minimum of air changes rate per hour within NATS cabin accommodations is 1.5ac/h or 2ac/h, but if windows opening are well controlled, the minimum air changes rate per hour is 0.5ac/h.

As it appears in figure16, if the air changes rate is higher, the total energy consumption would be higher as well. It is also the same situation for the figure following figure that shows the effect of increasing infiltration rate on total energy consumption/year: (external-wall: U-value = 0.76W/m^{2}K; and double glazing window: U-value: 2.75W/m^{2}K).

Figure17: *Impacts of increasing infiltration rates on the total energy delivered/year (U-value for ext.wall=0.76W/m^{2}K; U-value for double glazing window=2.75W/m^{2}K)*



If we compare the total energy delivered when the air infiltration rate is kept to a minimum (0.5ac/h) and the U-value for both external wall and double glazing window to 0.27W/m^{2}K and 1.7W/m^{2}K respectively, with the total energy delivered when the air infiltration is kept to the highest level (2ac/h) when the U-value for both external wall and double glazing window respectively is 0.67W/m^{2}K and 2.75W/m^{2}K, we could find the total energy saving of 32226.37kWh/year.

This result shows that by reducing air infiltration rate within cabins, and by combining improved insulation with reduced emissivity, one could save 54% of energy.

VII. Economic aspects

VII.1. Economic aspects on heating systems

For economic reasons, Laing'O Rourke has made some efforts to save energy on space heating by selecting and using energy efficient construction materials. However, there is still great potential to go further in reducing its expenditures on energy consumption.
In this research, a simulation analysis was undertaken using insulation and glazing materials with different coefficients of transmittance. The results show the best alternative, and they are presented in the following table:

Table21*: Impact of air changes variation on total savings/year*

Double glazing window: U-value (W/m^{2}K)	External wall: U-value (W/m^{2}K)	Minimum air changes rate (ac/h)	Total energy delivered (kWh)	Total energy costs/year (£)
2.75	0.35	0.5	31864.65	2549.17
		1.5	47846.67	3827.74
	0.76	0.5	39079.25	3126.34
		1.5	52907.71	4232.6
	0.67	1.5	51820.52	4145.64
		2	60327.85	4826.22

It is the responsibility for the company to select the option which is the most economical as well as consistent with the degree of safety and aesthetic value required. As shown in the table21, the elimination of cost for wasted energy results in savings that can be counted every year. For example by improving external walls insulation and double glazing windows for NATS cabins while keeping the air infiltration rate at the recommended minimum level (0.5ac/h), Laing' O Rourke could save energy and at the same time reduce CO_2 emissions from the environment.

The total savings/year on heating systems when the U-value of external walls and double glazing windows for NATS cabins are reduced to the optimum level is calculated as follows:

Annual savings (£...) on heating systems = Unit cost/kWh * Energy saved/year (kWh)

= £0.08 * 32226.37 = £2578.11
If Laing O'Rourke reduces on NATS cabins the U-value respectively to 0.27W/m^{2}k (for external walls) and to 1.7W/m^{2}K (for windows), it could save £2578.11 each year on heating systems.

The total amount of CO_2 emissions that could be saved is calculated by using DEFRA guidelines which are based on the product of the total energy saved and the CO_2 emissions factor. And the following formula is used.

$$CO_2 \text{ emissions (tonnes)} = \frac{EnergySaved(kWh) * FuelEmissionFactor(kgCO_2 / kWh)}{1000} \quad [18]$$

$$= \frac{32226.37kWh * 0.43kgCO_2 / kWh}{1000} = 13.86tonnesOfCO_2Emissions$$

If the heating in the NATS cabins is well controlled by a central thermostat, PIR sensors which control contactors on group of heaters in all heated spaces and central timer switches, the CO_2 emissions could be sensibly reduced. Consequently, significant improvement on the environment protection would be achieved.

VII.2. Economic aspects on lighting systems

VII.2.1. Introduction

A wide range of energy efficient measures are available for the lighting system in buildings, for which the financial and the environmental implications can vary considerably. It is very important to determine whether replacing an existing system with a new one results to better cost benefits. For example, evaluate the economic and environmental impacts of replacing an existing inefficient lamp with an energy saver one. With respect to the light sources, comparative costs can most readily studied on basis of quantity of lumens produced, since illumination also depends on fixture and the type of space, these vary with each installation.

The aim of this part is to determine the total savings at NATS cabin accommodation for the two lighting systems, namely the T5 and the T8 fluorescent tubes. On this point, an economic assessment taking into account the total costs and the environmental benefits, is to undertake in order to justify the selection of the best technology that minimize the pollution on one hand, and in other hand which save energy and therefore money.

VII.2.2. Payback period

The payback period is the length of time required to recover the capital investment out of the savings or earnings. When the time value of money is not considered, it is a ratio of the initial cost to the annual savings.
It is calculated as follow:

$$\text{Payback period} = \frac{CapitalCost}{AnnualSavings} \quad [1]$$

VII.2.3. Life Cycle Costing

The life cycle costing is an analysis of the total cost of owning; operating; and maintaining a planned project over its useful life. This analysis insists on the identification of all costs associated with the systems. It can be used also to determine whether a specific project is cost-effective or to compare the economic consequences of alternatives solutions. When comparing the alternative solutions to a particular problem, the system showing the lowest life cycle cost will usually be the first choice.

On NATS construction site, the lighting system is provided by T8 58W fluorescent tubes throughout the cabins. However, it is suggested to replace this type of lights with its equivalent called T5 49W, which is more energy efficient than T8 type. In this study, the two lighting systems (T8 58W and T5 49W) were compared, and the total lighting electricity savings and energy costs savings were quantified.

Table22: *Total savings on lighting system when replacing T8 58W to T5 49W fluorescent tubes*

Lamp type	T5 fluorescent tube	T8 fluorescent tube
Lamp wattage	49W	58W
Luminous efficacy	102lm/W	-
Rated luminous flux per lamp	5000lm	3700lm
Lamp life time	20,000hours	15,000hours
Installation costs (luminaires + gears)	£10	£10
Lamp costs	£19.38	£15
Electricity cost/kwh	£0.08/kWh	£0.08/kWh
Number of installations required in cabins at NATS	$\frac{140*3700}{5000}=104units\vert$	140units
Total installation costs	£(10*104) = £1040	£(10*140) = £1400
Burning hours over 3 years	3*48*7*20hours = 20160hrs	3*48*7*20hours = 20160hrs
Time each lamp is replaced in 3years	$\frac{20160hrs}{20000hrs}=1$	$\frac{20160hrs}{15000hrs}=1.344$
Replacement costs	£(19.38*1*104) = £2016	£(15*1.344*140) = £2822
Electrical energy use for each lamp	$\frac{49}{1000}kW*20160h=988kWh\vert$	$\frac{58}{1000}kW*20160h=1169kWh\vert$
Total electricity use	988kWh*104 = 102752kWh	1169kWh*140 = 163699kWh
Electricity costs	£0.08*102752 = £8220	£0.08*163699 = £13096
Running costs (replacement + electricity costs)	£(2016 + 8220) = £10236	£(2822 + 13096) = £15918
Total costs over 3years (installation costs + running costs)	£(1040 + 10236) = £11276	£(1400 + 15918) = £17318
Total saving over 3years	£(17318 – 11276) = £6042	

The total savings on lighting systems/year when replacing T8 58W to T5 49W fluorescent lamps: $\frac{£6042}{3}=£2014/year$

If NATS lighting system is controlled by switching off lights anytime they are not in use; and the existing lights (58W T8) are removed and replaced by the T5 49W, significant amount of money could be saved and the CO2 emissions could be reduced as it is shown below:

VII.2.4. Replacing T8 58W to T5 49W fluorescent lamps and switching on/off as necessary

In NATS cabin accommodations, there are in total 140lamps installed in offices; canteen; kitchen; drying rooms; toilets; etc. The lighting is often switched on unnecessarily in most areas which lead to the energy wastage. It is assumed in the calculations that lights are on 20hours a day 7days per week and 48weeks/year. However, it is suggested to reduce the amount of burning hours as much as possible in order to save energy, and propose to switch on 10hours a day; 5days a week and 48weeks per year [17]. This could reduce considerably the energy consumption; save money and protect the environment from greenhouse gases. Then, the total burning hours required over three years for NATS construction site to be illuminated without energy wastage is: 3*48*7*10hours = 7200hours.

- By turning on lights for only 10hours a day over three years, the total electricity use at NATS construction site is:

$$\frac{102752kWh}{20160h} * 7200h = 36697kWh$$

The lighting electricity saving over three years: 163699kWh – 36697kWh = 127002kWh

The electricity savings per year is: $\frac{127002kWh}{3} = 42334kWh$

The energy cost savings per year is: £0.08*42334 = £3387/year

- Also LORS could reduce CO_2 emissions from the environment, by switching on/off controls. The method for measuring CO_2 emissions from energy are based on the product of energy saved and CO_2 emissions factor (according to DEFRA method). The calculation of CO_2 emissions is made as follows:

CO2 emissions (tonnes) = $\frac{EnergySaved(kWh) * FuelEmissionFactor(kgCO_2 / kWh)}{1000}$ [18]

The total amount of CO_2 emissions that could be saved by switching on/off is:

$$\frac{42334kWh * 0.43kgCO_2 / kWh}{1000} = 18.2tonnesOfCO_2emissions$$

▪ By removing the existing T8 58W installed in cabin accommodations at NATS centre, and replacing T5 49W fluorescent tubes, Laing O'Rourke Scotland could reduce the total energy consumption. The total lighting electricity use is obtained by using the following formula:

Total electricity use = $\dfrac{TotalWatts * BurningHours}{1000}$

When the T8 58W are removed, and the T5 49W tubes are replaced at NATS construction site, the total electricity saved over three years is the difference between the electricity used by T8 58W tubes ,and that used by T5 49W over three years. That difference is:
163699kWh – 102752kWh = 60947kWh

The total lighting electricity savings /year when replacing T8 tubes to T5 tubes is:

$$\frac{60947kWh}{3} = 20316kWh$$

The total amount of CO_2 emissions that LORS could save when replacing the T5 49W lamps is: $\dfrac{20316kWh * 0.43kgCO_2 / kWh}{1000} = 8.74 tonnesOfCO_2Emissions$

By controlling the lighting systems at NATS cabin accommodations, using the switch on/off method as well as a high efficiency energy saver lamps (T5 49W), Laing O'Rourke Scotland could reduce from the environment the total amount of 26.9tonnes of CO_2 emissions. And its total energy costs savings per year when using this control system is: £2014 + £3387 = £5401/year

The payback period = $\dfrac{TotalInitialCosts}{EnergyCostSaving / year} = \dfrac{£11276}{£5401} = 2years$

Laing O'Rourke Scotland will recover its spending on lighting system over two years, when the energy consumption is properly controlled, and will also contribute to the environmental protection by reducing the CO_2 emissions to the surroundings areas.

VII.2.4.2. Conclusions and recommendations

It is worthwhile to remove the T8 58W and replace them with T5 49W fluorescent lamps powered by electronic ballasts and dimmed according to the amount of natural light inside the cabins. It is also important to install a lighting control system equipped with time scheduling, daylight and occupancy responsive devices, and take into account the idea of localised lighting and other measures such as a regular maintenance plan; the awareness of users (sub-contractors) and the alternative of turning off the lighting systems. By this way, the lighting electricity savings would be £5401/year, and the lighting quality improved.

Further to the lighting control system that can dim the lamp's output in response to the daylight availability, it is also necessary to substitute the conventional high-loss magnetic ballasts with the electronic ballasts, because even for the same lamp wattage, the inrush current of electronic ballasts is, in principle, higher than that of the conventional ballasts. So, no special provision is required for electronic ballasts to be made for inrush current at starting. The energy savings could be improved on this case as well as the visual conditions of the users.

The lighting control systems could be different for outside and inside of the building. Inside the buildings, the occupancy and daylight responsive systems could be used, while the outdoor lighting is geared with timers. The lighting in the meeting rooms are continuously operating during the day unnecessarily. Therefore, occupancy sensors which could switch off the lighting when there is nobody in the rooms should be installed.

In brief, by applying the lighting system equipped with new control devices such as occupancy sensors; photo-sensors; timers with the tele-control capabilities, one could reduce considerably the yearly burning hours. And so, the lighting savings and energy costs savings will increase.

VIII. Conclusion and Recommendations for future work

Applying proven energy efficient technologies with proper energy management offer significant rewards. This helps to reduce or eliminate energy wastage; to ensure whether the company's operations are more productive and, improve the quality of its businesses and management; and to prevent the environmental pollution.

Laing O'Rourke has so far done some improvement in reducing energy consumption on NATS cabin accommodations. It has achieved energy costs avoidance results by improving external wall insulation from the conventional U-value ($0.67W/m^2K$) to the external wall U-value ($0.35W/m^2K$) recommended by the UK new building regulations [23], and saved £2277.05/year on heating systems; and on the same time reduced 12.24 tonnes of CO2 emissions/year from the environment. If the existing lighting fluorescent tubes (T8 58W) is replaced with the most energy efficient fluorescent tubes (T5 49W), and lighting control is improved, 27tonnes of CO_2 emissions/year could be reduced and £5401/year could be saved.

There is still great potential to go further in reducing energy costs by using new energy efficient technologies, with good management. At present, the lack of automatic controls of heating and lighting systems in some areas, and the improper energy management such as leaving a room with heaters and lights switched on, and opening windows unnecessarily results in significant energy wastage on NATS construction site.

Briefly, improving thermal insulation and glazing systems, reducing ventilation air quantities and lowering lighting levels can make an important contribution to energy savings in temporary accommodation. Added to this, designing an accommodation for the economically optimum level of thermal self-efficiency will not only minimize annual energy costs, but in most cases will also stabilize the interior surface temperature of the envelope, resulting in more uniform interior conditions and greater comfort.

For further improvement on energy savings, the following are recommended:

▪ Ventilation systems should be scheduled so that the exhaust system operates only when it is required. And the outdoor air supplied within cabins should be reduced to minimum local requirements and the exhaust requirements should be balanced to maintain a slight positive pressure, retarding air infiltration and thereby reducing heat losses or heat gains.

The major fuel use on construction sites is diesel for construction plants where it is estimated that 75% to 80% of fuel use occurs. The remaining fuel use is mostly electricity, some from temporary main supplies but mostly from diesel generators. When the number and types of plant equipment are taken into account, these electrical consumption figures represent only 20% to 25% of the total energy consumed on construction site. The major energy users on site are construction plants such as backhoe loaders; dampers; hydraulic excavators; cranes; etc. [17]

At present, there is no method on LORS construction sites of logging diesel consumption on generators, and no method of keeping an accurate log of energy consumption at NATS construction site. This lack of any real knowledge of energy use prohibits any appraisal of the value of energy efficiency measures taken, and to quantify the total energy used on construction site. [17]

Due to the lack of real figures related to the total fuel consumed in litres of diesel, the current study had to be limited to the total energy consumed within cabin accommodations. So, it is suggested that future work could identify the total fuel use and running hours for each item of plant equipment on the construction site, analyse the fuel consumption variation for each plant over a period of a year and identify why exceptional fuel consumption has occurred. From this, one could establish whether the amount of energy use is normal and set targets for improvement.

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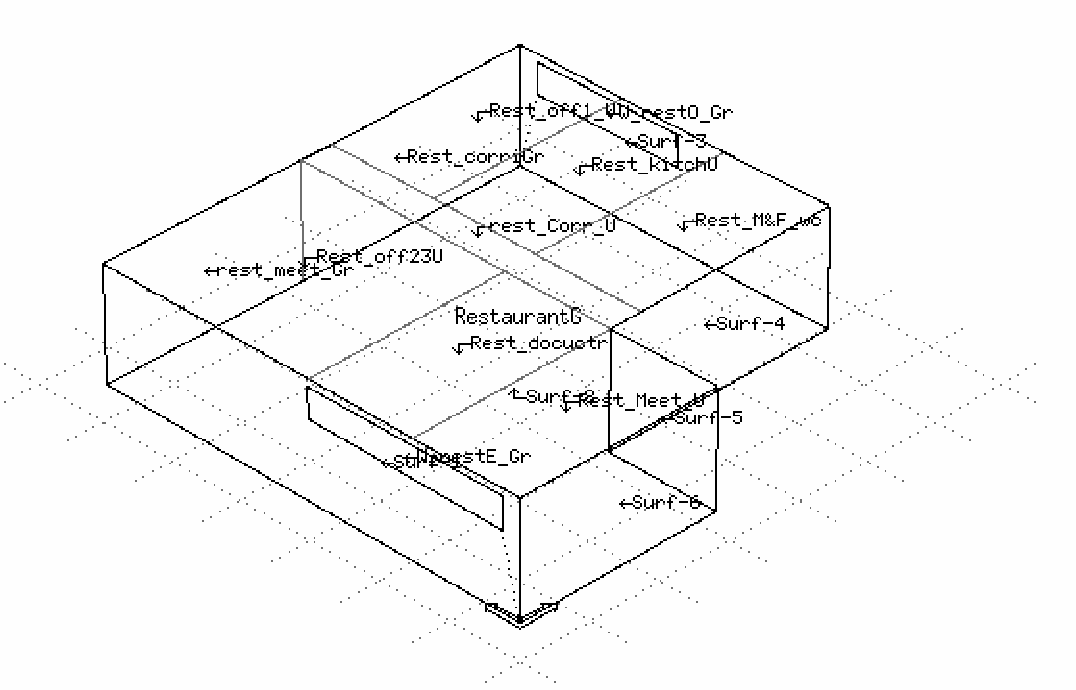
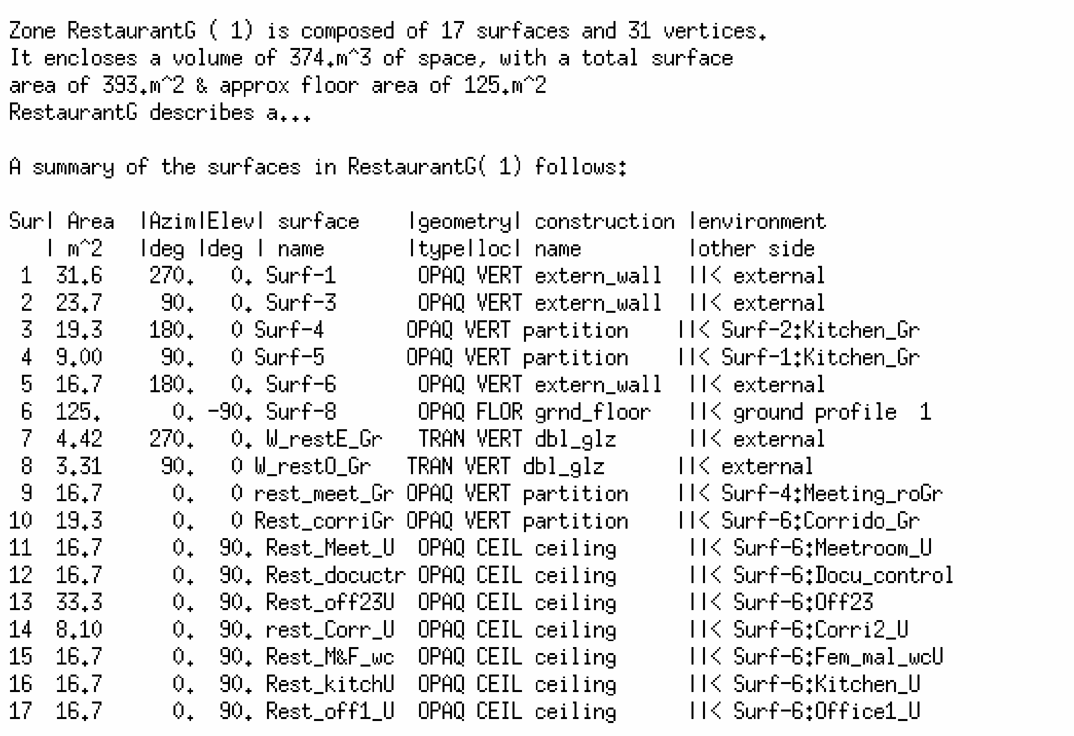
APPENDIX: Simulation results for one of the 28 zones (restaurantG)

1. Geometry & attributions for the zone (1)

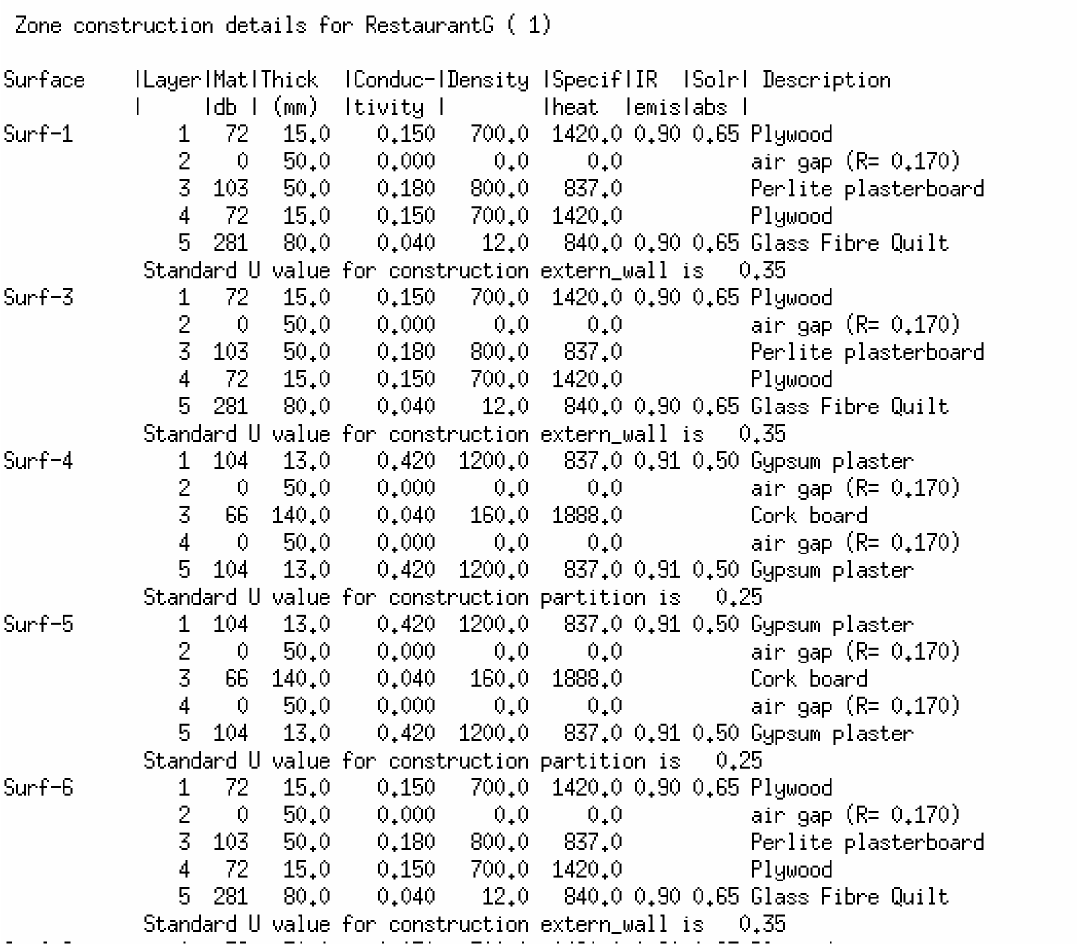


2. Summary description for RestaurantG

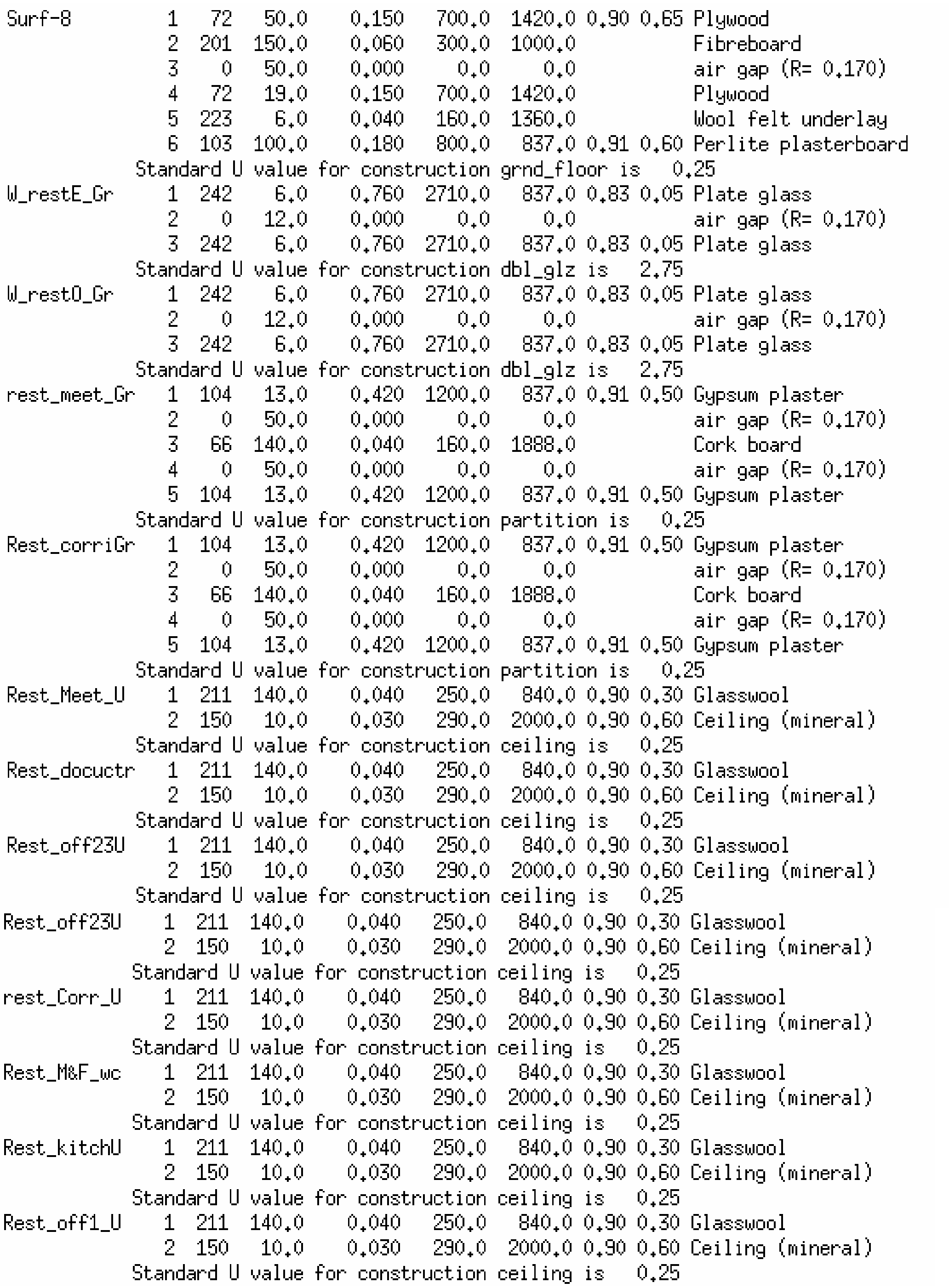


```
Zone RestaurantG ( 1) is composed of 17 surfaces and 31 vertices.
It encloses a volume of 374.m^3 of space, with a total surface
area of 393.m^2 & approx floor area of 125.m^2
RestaurantG describes a...

A summary of the surfaces in RestaurantG( 1) follows:

Sur| Area  |Azim|Elev| surface    |geometry| construction |environment
   | m^2   |deg |deg | name       |type|loc| name         |other side
 1  31.6    270.   0. Surf-1       OPAQ VERT extern_wall  ||< external
 2  23.7     90.   0. Surf-3       OPAQ VERT extern_wall  ||< external
 3  19.3    180.   0 Surf-4       OPAQ VERT partition    ||< Surf-2:Kitchen_Gr
 4  9.00     90.   0 Surf-5       OPAQ VERT partition    ||< Surf-1:Kitchen_Gr
 5  16.7    180.   0. Surf-6       OPAQ VERT extern_wall  ||< external
 6  125.      0. -90. Surf-8       OPAQ FLOR grnd_floor   ||< ground profile  1
 7  4.42    270.   0. W_restE_Gr   TRAN VERT dbl_glz      ||< external
 8  3.31     90.   0 W_restO_Gr   TRAN VERT dbl_glz      ||< external
 9  16.7      0.   0 rest_meet_Gr OPAQ VERT partition    ||< Surf-4:Meeting_roGr
10  19.3      0.   0 Rest_corriGr OPAQ VERT partition    ||< Surf-6:Corrido_Gr
11  16.7      0.  90. Rest_Meet_U  OPAQ CEIL ceiling      ||< Surf-6:Meetroom_U
12  16.7      0.  90. Rest_docuctr OPAQ CEIL ceiling      ||< Surf-6:Docu_control
13  33.3      0.  90. Rest_off23U  OPAQ CEIL ceiling      ||< Surf-6:Off23
14  8.10      0.  90. rest_Corr_U  OPAQ CEIL ceiling      ||< Surf-6:Corri2_U
15  16.7      0.  90. Rest_M&F_wc  OPAQ CEIL ceiling      ||< Surf-6:Fem_mal_wcU
16  16.7      0.  90. Rest_kitchU  OPAQ CEIL ceiling      ||< Surf-6:Kitchen_U
17  16.7      0.  90. Rest_off1_U  OPAQ CEIL ceiling      ||< Surf-6:Office1_U
```

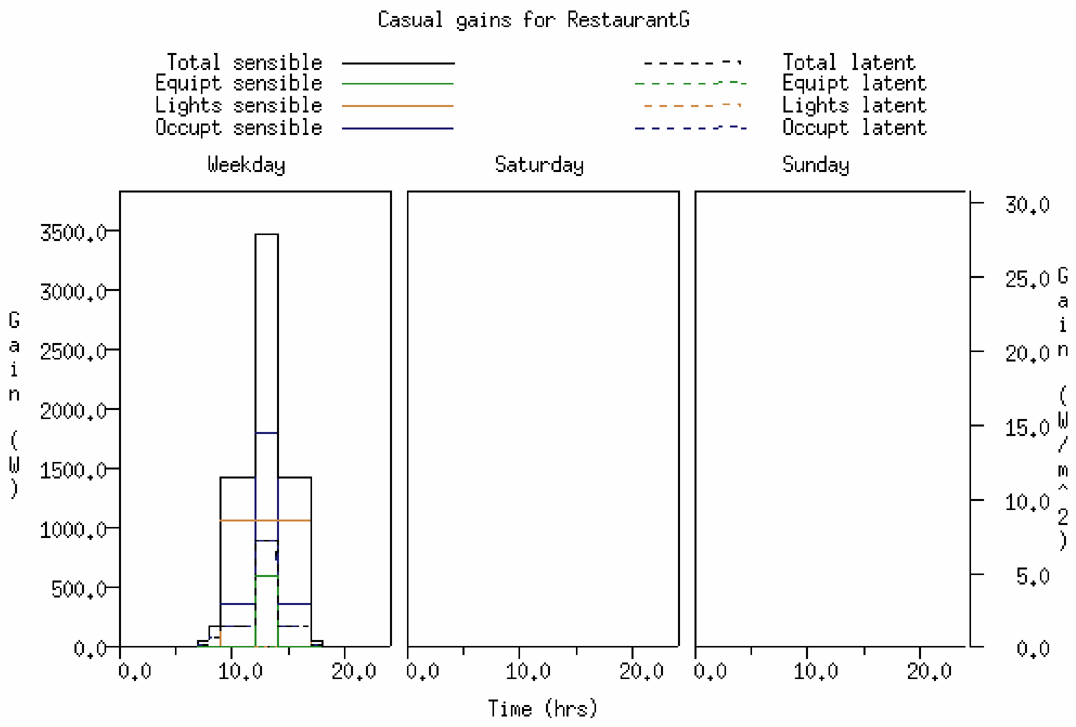
3. Multi-layer constructions used



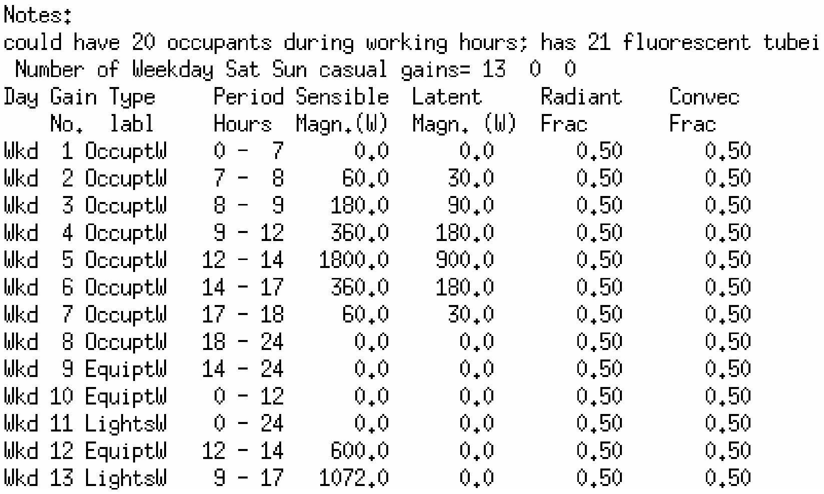
```
 Zone construction details for RestaurantG ( 1)

Surface    |Layer|Mat|Thick  |Conduc-|Density |Specif|IR  |Solr| Description
           |     |db | (mm)  |tivity |        |heat  |emis|abs |
Surf-1         1   72   15.0    0.150   700.0  1420.0 0.90 0.65 Plywood
               2    0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
               3  103   50.0    0.180   800.0   837.0           Perlite plasterboard
               4   72   15.0    0.150   700.0  1420.0           Plywood
               5  281   80.0    0.040    12.0   840.0 0.90 0.65 Glass Fibre Quilt
            Standard U value for construction extern_wall is   0.35
Surf-3         1   72   15.0    0.150   700.0  1420.0 0.90 0.65 Plywood
               2    0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
               3  103   50.0    0.180   800.0   837.0           Perlite plasterboard
               4   72   15.0    0.150   700.0  1420.0           Plywood
               5  281   80.0    0.040    12.0   840.0 0.90 0.65 Glass Fibre Quilt
            Standard U value for construction extern_wall is   0.35
Surf-4         1  104   13.0    0.420  1200.0   837.0 0.91 0.50 Gypsum plaster
               2    0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
               3   66  140.0    0.040   160.0  1888.0           Cork board
               4    0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
               5  104   13.0    0.420  1200.0   837.0 0.91 0.50 Gypsum plaster
            Standard U value for construction partition is   0.25
Surf-5         1  104   13.0    0.420  1200.0   837.0 0.91 0.50 Gypsum plaster
               2    0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
               3   66  140.0    0.040   160.0  1888.0           Cork board
               4    0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
               5  104   13.0    0.420  1200.0   837.0 0.91 0.50 Gypsum plaster
            Standard U value for construction partition is   0.25
Surf-6         1   72   15.0    0.150   700.0  1420.0 0.90 0.65 Plywood
               2    0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
               3  103   50.0    0.180   800.0   837.0           Perlite plasterboard
               4   72   15.0    0.150   700.0  1420.0           Plywood
               5  281   80.0    0.040    12.0   840.0 0.90 0.65 Glass Fibre Quilt
            Standard U value for construction extern_wall is   0.35
```



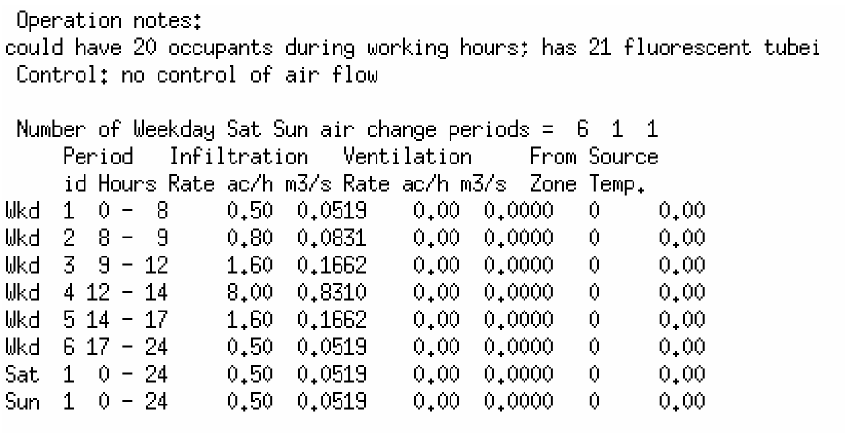
```
Surf-8        1  72   50.0    0.150   700.0  1420.0 0.90 0.65 Plywood
              2 201  150.0    0.060   300.0  1000.0           Fibreboard
              3   0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
              4  72   19.0    0.150   700.0  1420.0           Plywood
              5 223    6.0    0.040   160.0  1360.0           Wool felt underlay
              6 103  100.0    0.180   800.0   837.0 0.91 0.60 Perlite plasterboard
          Standard U value for construction grnd_floor is   0.25
W_restE_Gr    1 242    6.0    0.760  2710.0   837.0 0.83 0.05 Plate glass
              2   0   12.0    0.000     0.0     0.0           air gap (R= 0.170)
              3 242    6.0    0.760  2710.0   837.0 0.83 0.05 Plate glass
          Standard U value for construction dbl_glz is   2.75
W_restO_Gr    1 242    6.0    0.760  2710.0   837.0 0.83 0.05 Plate glass
              2   0   12.0    0.000     0.0     0.0           air gap (R= 0.170)
              3 242    6.0    0.760  2710.0   837.0 0.83 0.05 Plate glass
          Standard U value for construction dbl_glz is   2.75
rest_meet_Gr  1 104   13.0    0.420  1200.0   837.0 0.91 0.50 Gypsum plaster
              2   0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
              3  66  140.0    0.040   160.0  1888.0           Cork board
              4   0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
              5 104   13.0    0.420  1200.0   837.0 0.91 0.50 Gypsum plaster
          Standard U value for construction partition is   0.25
Rest_corriGr  1 104   13.0    0.420  1200.0   837.0 0.91 0.50 Gypsum plaster
              2   0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
              3  66  140.0    0.040   160.0  1888.0           Cork board
              4   0   50.0    0.000     0.0     0.0           air gap (R= 0.170)
              5 104   13.0    0.420  1200.0   837.0 0.91 0.50 Gypsum plaster
          Standard U value for construction partition is   0.25
Rest_Meet_U   1 211  140.0    0.040   250.0   840.0 0.90 0.30 Glasswool
              2 150   10.0    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
          Standard U value for construction ceiling is   0.25
Rest_docuctr  1 211  140.0    0.040   250.0   840.0 0.90 0.30 Glasswool
              2 150   10.0    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
          Standard U value for construction ceiling is   0.25
Rest_off23U   1 211  140.0    0.040   250.0   840.0 0.90 0.30 Glasswool
              2 150   10.0    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
          Standard U value for construction ceiling is   0.25
Rest_off23U   1 211  140.0    0.040   250.0   840.0 0.90 0.30 Glasswool
              2 150   10.0    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
          Standard U value for construction ceiling is   0.25
rest_Corr_U   1 211  140.0    0.040   250.0   840.0 0.90 0.30 Glasswool
              2 150   10.0    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
          Standard U value for construction ceiling is   0.25
Rest_M&F_wc   1 211  140.0    0.040   250.0   840.0 0.90 0.30 Glasswool
              2 150   10.0    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
          Standard U value for construction ceiling is   0.25
Rest_kitchU   1 211  140.0    0.040   250.0   840.0 0.90 0.30 Glasswool
              2 150   10.0    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
          Standard U value for construction ceiling is   0.25
Rest_off1_U   1 211  140.0    0.040   250.0   840.0 0.90 0.30 Glasswool
              2 150   10.0    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
          Standard U value for construction ceiling is   0.25
```



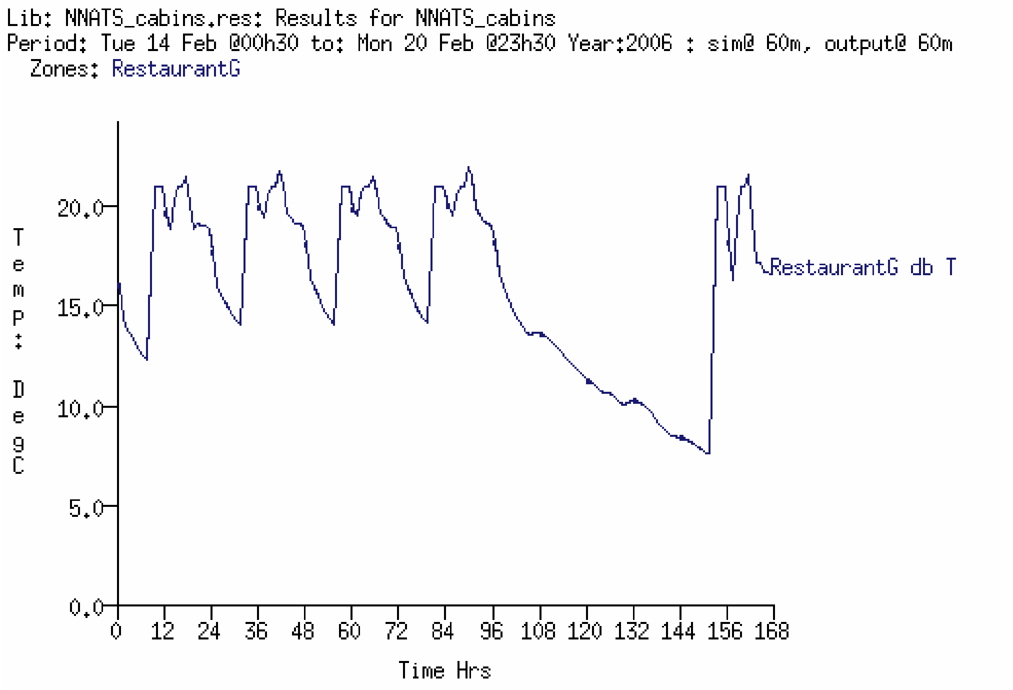
5. Operation notes:



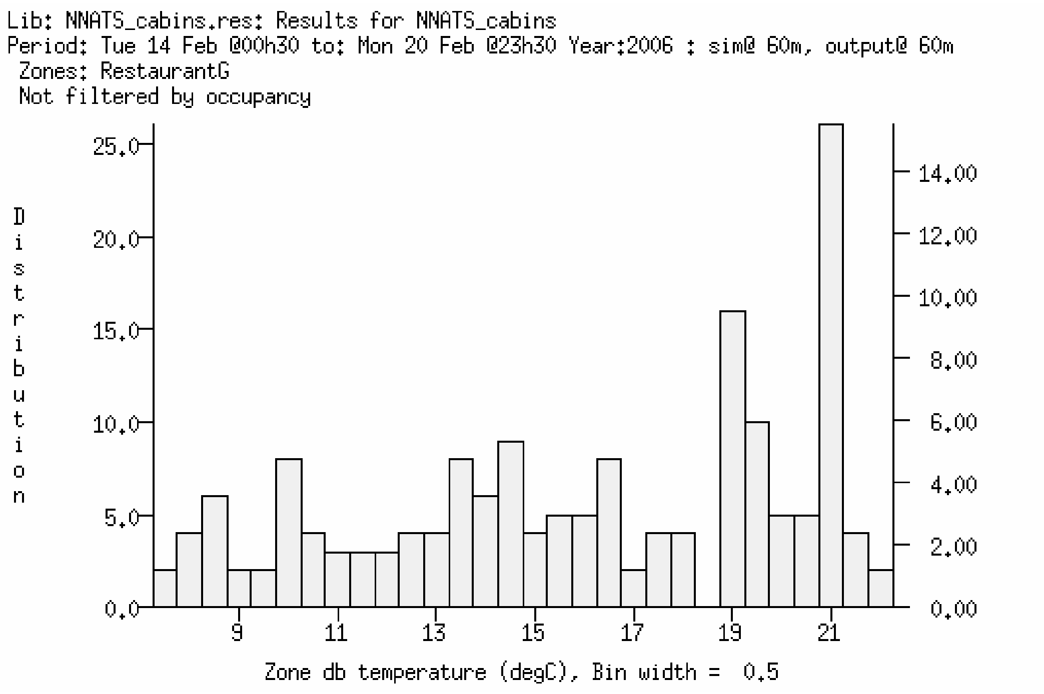
```
Notes:
could have 20 occupants during working hours; has 21 fluorescent tubei
 Number of Weekday Sat Sun casual gains= 13  0  0
Day Gain Type      Period Sensible  Latent     Radiant     Convec
    No.  labl      Hours  Magn.(W)  Magn. (W)  Frac        Frac
Wkd  1 OccuptW     0 -  7     0.0      0.0        0.50        0.50
Wkd  2 OccuptW     7 -  8    60.0     30.0        0.50        0.50
Wkd  3 OccuptW     8 -  9   180.0     90.0        0.50        0.50
Wkd  4 OccuptW     9 - 12   360.0    180.0        0.50        0.50
Wkd  5 OccuptW    12 - 14  1800.0    900.0        0.50        0.50
Wkd  6 OccuptW    14 - 17   360.0    180.0        0.50        0.50
Wkd  7 OccuptW    17 - 18    60.0     30.0        0.50        0.50
Wkd  8 OccuptW    18 - 24     0.0      0.0        0.50        0.50
Wkd  9 EquiptW    14 - 24     0.0      0.0        0.50        0.50
Wkd 10 EquiptW     0 - 12     0.0      0.0        0.50        0.50
Wkd 11 LightsW     0 - 24     0.0      0.0        0.50        0.50
Wkd 12 EquiptW    12 - 14   600.0      0.0        0.50        0.50
Wkd 13 LightsW     9 - 17  1072.0      0.0        0.50        0.50
```



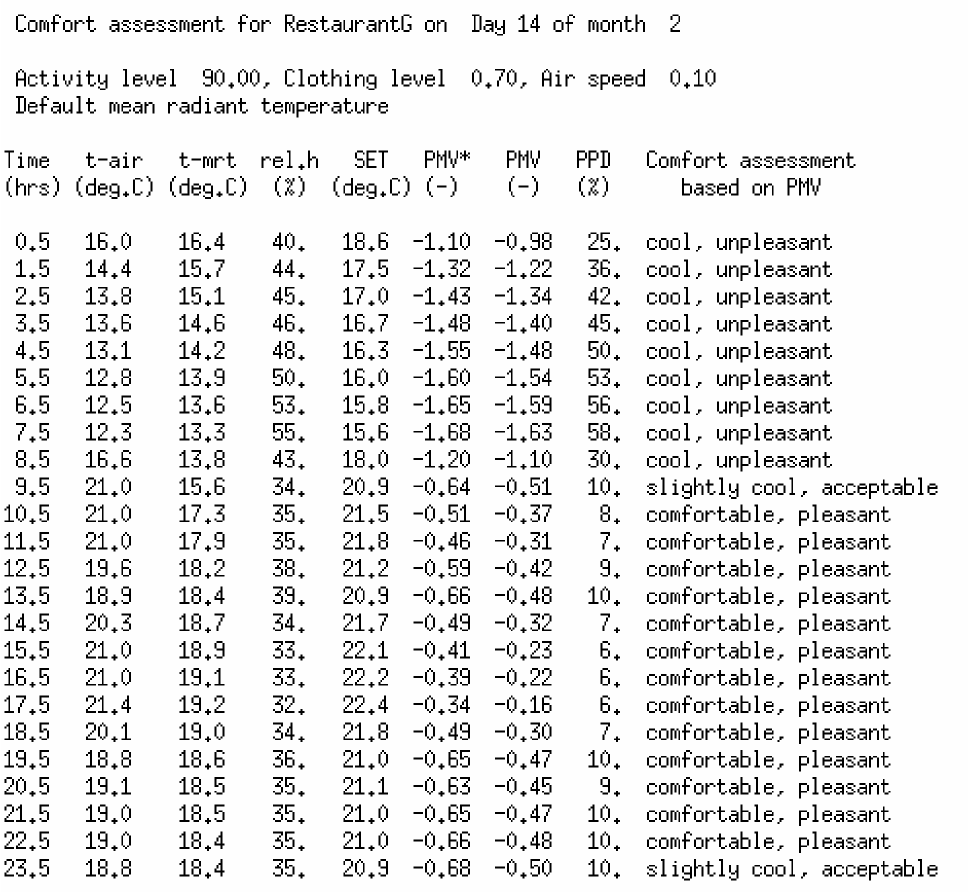
```
 Operation notes:
could have 20 occupants during working hours; has 21 fluorescent tubei
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  6  1  1
     Period    Infiltration    Ventilation     From Source
     id Hours Rate ac/h m3/s Rate ac/h m3/s  Zone Temp.
Wkd  1  0 -  8     0.50  0.0519    0.00  0.0000   0     0.00
Wkd  2  8 -  9     0.80  0.0831    0.00  0.0000   0     0.00
Wkd  3  9 - 12     1.60  0.1662    0.00  0.0000   0     0.00
Wkd  4 12 - 14     8.00  0.8310    0.00  0.0000   0     0.00
Wkd  5 14 - 17     1.60  0.1662    0.00  0.0000   0     0.00
Wkd  6 17 - 24     0.50  0.0519    0.00  0.0000   0     0.00
Sat  1  0 - 24     0.50  0.0519    0.00  0.0000   0     0.00
Sun  1  0 - 24     0.50  0.0519    0.00  0.0000   0     0.00
```



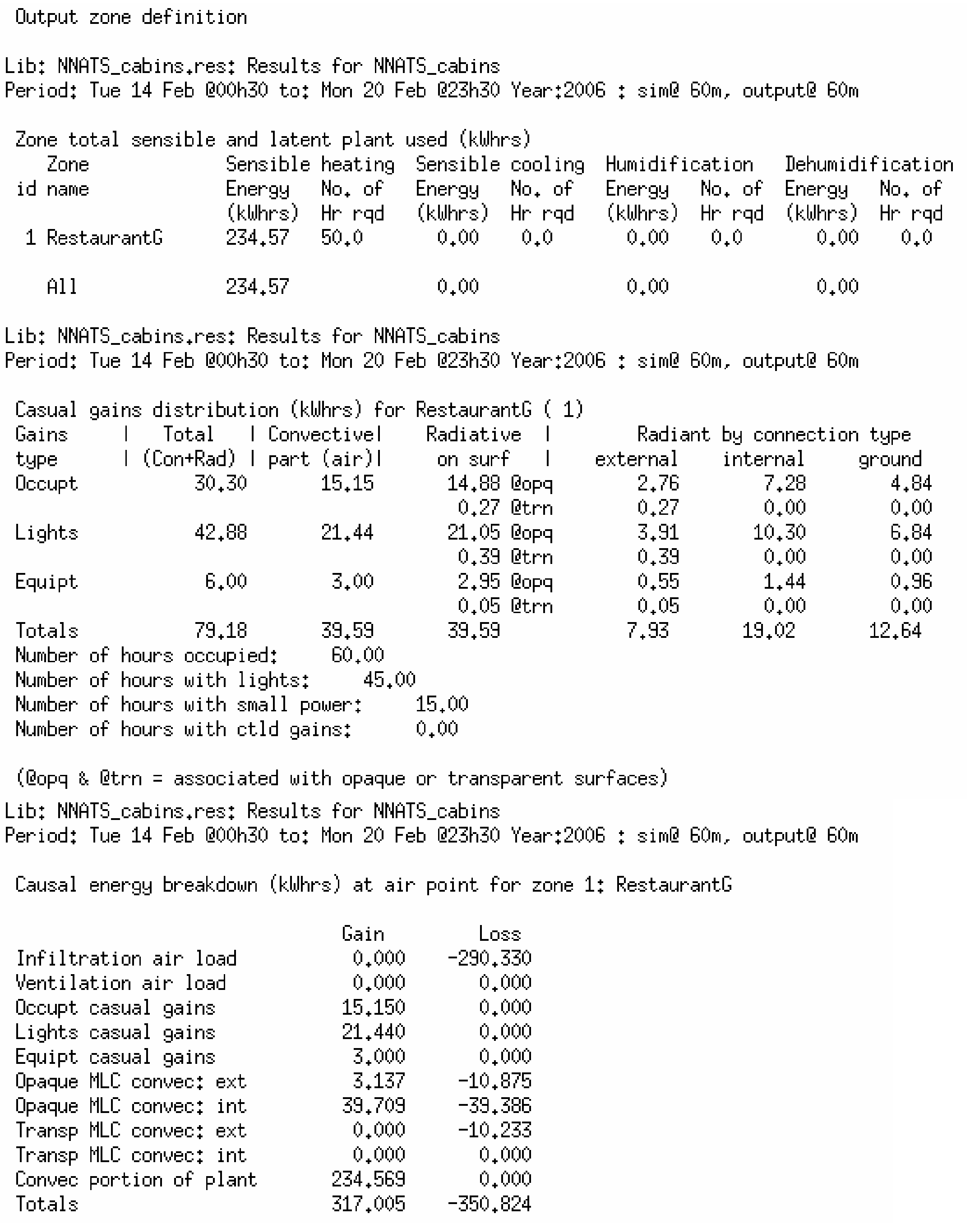
```
Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m
  Zones: RestaurantG
```



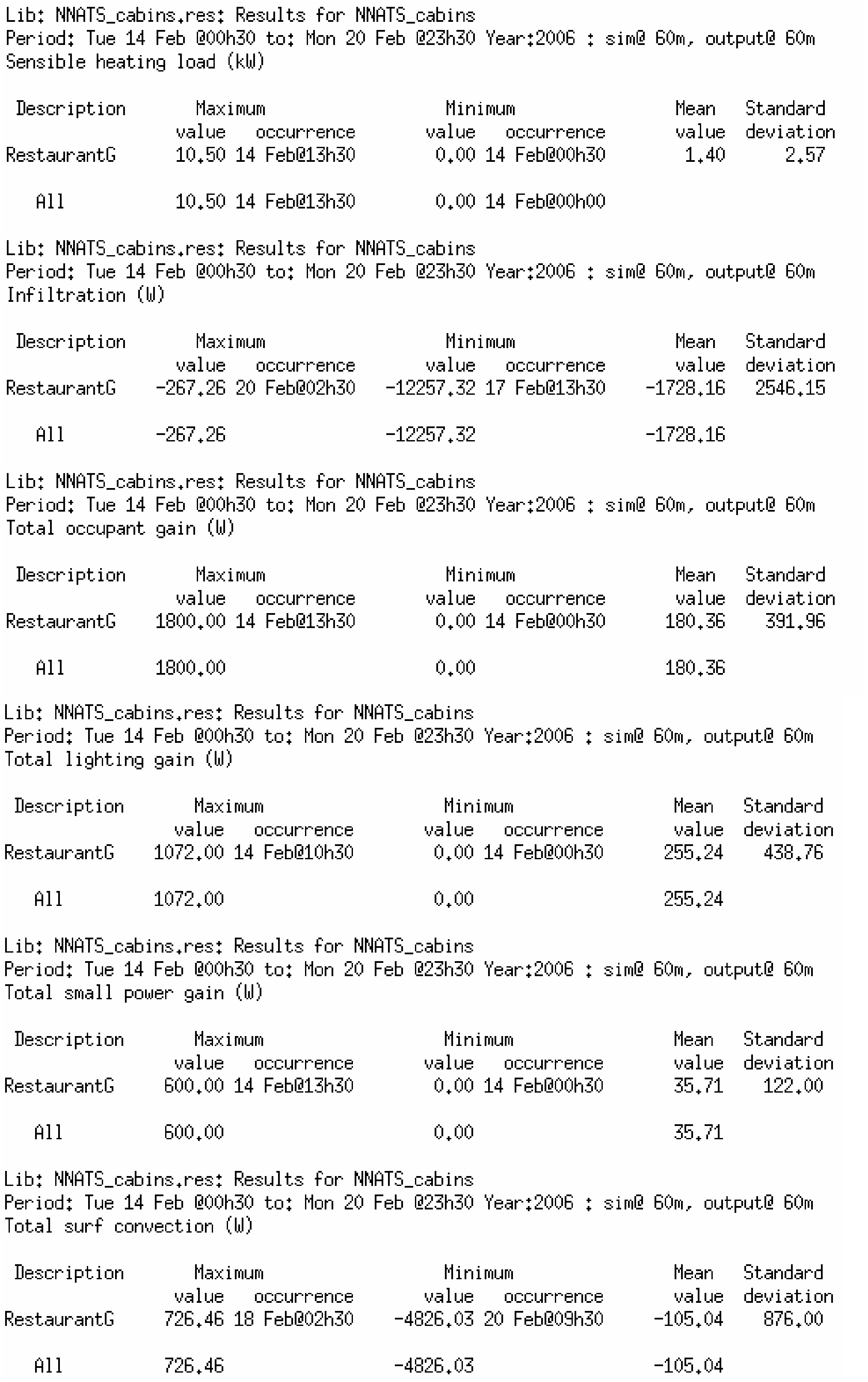
```
Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m
 Zones: RestaurantG
 Not filtered by occupancy
```



```
 Comfort assessment for RestaurantG on  Day 14 of month  2

 Activity level  90.00, Clothing level  0.70, Air speed  0.10
 Default mean radiant temperature

Time   t-air   t-mrt  rel.h   SET   PMV*   PMV   PPD  Comfort assessment
(hrs) (deg.C) (deg.C)  (%)  (deg.C) (-)    (-)   (%)     based on PMV

 0.5   16.0    16.4    40.   18.6  -1.10  -0.98  25.  cool, unpleasant
 1.5   14.4    15.7    44.   17.5  -1.32  -1.22  36.  cool, unpleasant
 2.5   13.8    15.1    45.   17.0  -1.43  -1.34  42.  cool, unpleasant
 3.5   13.6    14.6    46.   16.7  -1.48  -1.40  45.  cool, unpleasant
 4.5   13.1    14.2    48.   16.3  -1.55  -1.48  50.  cool, unpleasant
 5.5   12.8    13.9    50.   16.0  -1.60  -1.54  53.  cool, unpleasant
 6.5   12.5    13.6    53.   15.8  -1.65  -1.59  56.  cool, unpleasant
 7.5   12.3    13.3    55.   15.6  -1.68  -1.63  58.  cool, unpleasant
 8.5   16.6    13.8    43.   18.0  -1.20  -1.10  30.  cool, unpleasant
 9.5   21.0    15.6    34.   20.9  -0.64  -0.51  10.  slightly cool, acceptable
10.5   21.0    17.3    35.   21.5  -0.51  -0.37   8.  comfortable, pleasant
11.5   21.0    17.9    35.   21.8  -0.46  -0.31   7.  comfortable, pleasant
12.5   19.6    18.2    38.   21.2  -0.59  -0.42   9.  comfortable, pleasant
13.5   18.9    18.4    39.   20.9  -0.66  -0.48  10.  comfortable, pleasant
14.5   20.3    18.7    34.   21.7  -0.49  -0.32   7.  comfortable, pleasant
15.5   21.0    18.9    33.   22.1  -0.41  -0.23   6.  comfortable, pleasant
16.5   21.0    19.1    33.   22.2  -0.39  -0.22   6.  comfortable, pleasant
17.5   21.4    19.2    32.   22.4  -0.34  -0.16   6.  comfortable, pleasant
18.5   20.1    19.0    34.   21.8  -0.49  -0.30   7.  comfortable, pleasant
19.5   18.8    18.6    36.   21.0  -0.65  -0.47  10.  comfortable, pleasant
20.5   19.1    18.5    35.   21.1  -0.63  -0.45   9.  comfortable, pleasant
21.5   19.0    18.5    35.   21.0  -0.65  -0.47  10.  comfortable, pleasant
22.5   19.0    18.4    35.   21.0  -0.66  -0.48  10.  comfortable, pleasant
23.5   18.8    18.4    35.   20.9  -0.68  -0.50  10.  slightly cool, acceptable
```

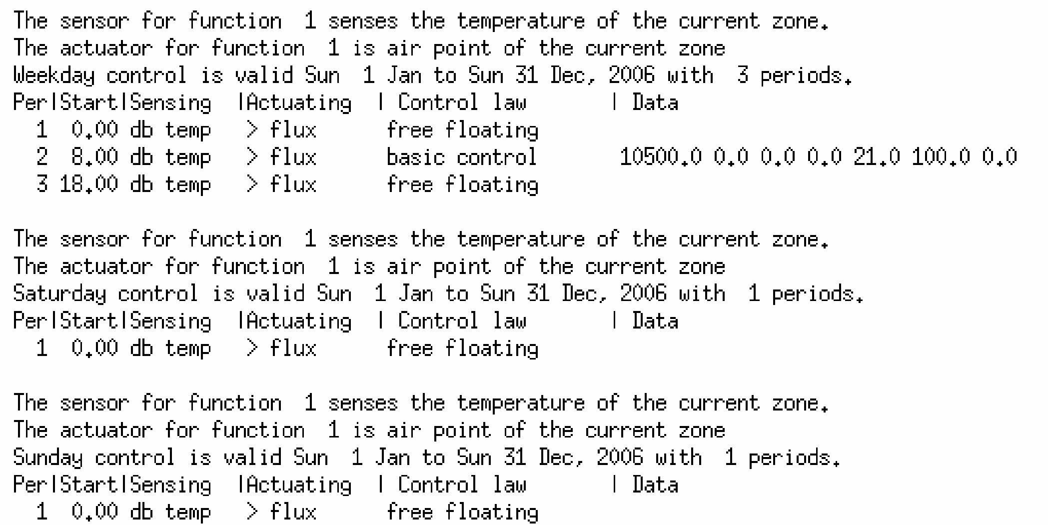


```
 Output zone definition

Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m

 Zone total sensible and latent plant used (kWhrs)
    Zone            Sensible heating  Sensible cooling  Humidification   Dehumidification
 id name            Energy   No. of   Energy   No. of   Energy   No. of  Energy   No. of
                    (kWhrs)  Hr rqd   (kWhrs)  Hr rqd   (kWhrs)  Hr rqd  (kWhrs)  Hr rqd
  1 RestaurantG     234.57   50.0       0.00    0.0       0.00    0.0       0.00    0.0

    All             234.57              0.00              0.00              0.00

Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m

 Casual gains distribution (kWhrs) for RestaurantG ( 1)
 Gains     |   Total   | Convective|    Radiative  |       Radiant by connection type
 type      | (Con+Rad) | part (air)|     on surf   |    external    internal     ground
 Occupt          30.30       15.15       14.88 @opq        2.76        7.28        4.84
                                          0.27 @trn        0.27        0.00        0.00
 Lights          42.88       21.44       21.05 @opq        3.91       10.30        6.84
                                          0.39 @trn        0.39        0.00        0.00
 Equipt           6.00        3.00        2.95 @opq        0.55        1.44        0.96
                                          0.05 @trn        0.05        0.00        0.00
 Totals          79.18       39.59       39.59             7.93       19.02       12.64
 Number of hours occupied:     60.00
 Number of hours with lights:     45.00
 Number of hours with small power:     15.00
 Number of hours with ctld gains:      0.00

 (@opq & @trn = associated with opaque or transparent surfaces)
Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m

 Causal energy breakdown (kWhrs) at air point for zone 1: RestaurantG

                              Gain        Loss
 Infiltration air load         0.000    -290.330
 Ventilation air load          0.000       0.000
 Occupt casual gains          15.150       0.000
 Lights casual gains          21.440       0.000
 Equipt casual gains           3.000       0.000
 Opaque MLC convec: ext        3.137     -10.875
 Opaque MLC convec: int       39.709     -39.386
 Transp MLC convec: ext        0.000     -10.233
 Transp MLC convec: int        0.000       0.000
 Convec portion of plant     234.569       0.000
 Totals                      317.005    -350.824
```



```
Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m
Sensible heating load (kW)

 Description       Maximum                 Minimum               Mean   Standard
                value   occurrence      value   occurrence      value  deviation
RestaurantG     10.50 14 Feb@13h30       0.00 14 Feb@00h30       1.40      2.57

   All          10.50 14 Feb@13h30       0.00 14 Feb@00h00

Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m
Infiltration (W)

 Description       Maximum                 Minimum               Mean   Standard
                value   occurrence      value   occurrence      value  deviation
RestaurantG   -267.26 20 Feb@02h30   -12257.32 17 Feb@13h30   -1728.16   2546.15

   All        -267.26                -12257.32                -1728.16

Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m
Total occupant gain (W)

 Description       Maximum                 Minimum               Mean   Standard
                value   occurrence      value   occurrence      value  deviation
RestaurantG   1800.00 14 Feb@13h30       0.00 14 Feb@00h30     180.36    391.96

   All        1800.00                    0.00                  180.36

Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m
Total lighting gain (W)

 Description       Maximum                 Minimum               Mean   Standard
                value   occurrence      value   occurrence      value  deviation
RestaurantG   1072.00 14 Feb@10h30       0.00 14 Feb@00h30     255.24    438.76

   All        1072.00                    0.00                  255.24

Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m
Total small power gain (W)

 Description       Maximum                 Minimum               Mean   Standard
                value   occurrence      value   occurrence      value  deviation
RestaurantG    600.00 14 Feb@13h30       0.00 14 Feb@00h30      35.71    122.00

   All         600.00                    0.00                   35.71

Lib: NNATS_cabins.res: Results for NNATS_cabins
Period: Tue 14 Feb @00h30 to: Mon 20 Feb @23h30 Year:2006 : sim@ 60m, output@ 60m
Total surf convection (W)

 Description       Maximum                 Minimum               Mean   Standard
                value   occurrence      value   occurrence      value  deviation
RestaurantG    726.46 18 Feb@02h30    -4826.03 20 Feb@09h30    -105.04    876.00

   All         726.46                 -4826.03                 -105.04
```

Control description:



```
The sensor for function  1 senses the temperature of the current zone.
The actuator for function  1 is air point of the current zone
Weekday control is valid Sun  1 Jan to Sun 31 Dec, 2006 with  3 periods.
Per|Start|Sensing  |Actuating  | Control law       | Data
  1  0.00 db temp   > flux      free floating
  2  8.00 db temp   > flux      basic control       10500.0 0.0 0.0 0.0 21.0 100.0 0.0
  3 18.00 db temp   > flux      free floating

The sensor for function  1 senses the temperature of the current zone.
The actuator for function  1 is air point of the current zone
Saturday control is valid Sun  1 Jan to Sun 31 Dec, 2006 with  1 periods.
Per|Start|Sensing  |Actuating  | Control law       | Data
  1  0.00 db temp   > flux      free floating

The sensor for function  1 senses the temperature of the current zone.
The actuator for function  1 is air point of the current zone
Sunday control is valid Sun  1 Jan to Sun 31 Dec, 2006 with  1 periods.
Per|Start|Sensing  |Actuating  | Control law       | Data
  1  0.00 db temp   > flux      free floating
```