DETERMINATION OF BUILDING COOLING LOADS USING REAL WEATHER DATA

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PREFACE

This thesis is submitted in partial fulfillment of the requirements of Sheffield Hallam University for the degree of Master of Philosophy.

It contains an account of research carried out between September 1994 and December 1997 in the School of Engineering, Sheffield Hallam University, under the supervision of Dr. M. J. Denman, Dr. I. W. Eames from University of Nottingham, Dr. K. P. Zachariah from University of Sheffield and Prof. G. R. Symmons from Sheffield Hallam University. Except where acknowledge and reference is appropriately made, this work is, original and has been carried out independently. No part of this thesis has been, or is currently being submitted for any degree or diploma at this, or any other university.

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Abstract

The main objective of this study is to develop a new computer based tool for use by engineers when designing and selecting an air conditioning system. Moreover, the design of the developed model must be robust enough for it to be implemented in the design stage of the building. Therefore this study was initiated to overcome some of the problems that were encountered using the well-established cooling load method.

For instance, cooling load calculations of a building are dependent on the external dynamic environmental factors. The load on the building is also affected by the internal dynamic environmental factors, in addition to the presence of the building envelope and its harmonics due to time lags. On the other hand, the application of using daily weather data in calculating the cooling load as well as the dynamic internal and external environmental factors is difficult to carry out manually because of the tediousness of the repetitive calculation which can deter designers from attempting detailed load profiling and this can result in more inaccurate estimates. For this reason, a dynamic model has been developed to account for the harmonic nature of the cooling load components on an hourly basis.

A computer model was constructed to carry out the calculations and to test the results. The CLTD/CLF method was used for the model because of its flexibility. Moreover, the dynamic behaviour of the model can be used to compare results from different building designs obtained from this study. These results showed that the real load profiles were superior to the profile from using the static traditional method.

Results from the analysis of the new method can clearly demonstrate the use of the computer program and allow variations in cooling load, peak and minimum load to be observed. Presenting the results in this way will enable a designer to size and to select the type of machine and predict the planned maintenance periods. Moreover, the program allows for effects of climate change on the performance of building cooling systems to be simulated.

Application of Qbasic programming with the CLTD/CLF method in combination with the Sinusoidal equation was also been used to account for the weather harmonics. The use of real weather data also allows the designer to see typical patterns of plant usage. If global warming becomes a reality we can use the computer program to predict how changes in weather patterns will effect cooling systems and can plan accordingly.

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Publication Arising from Thesis:

F. S. Abdul Kadir, M. J. Denman, I. W. Eames, K. P. Zachariah.

"Prediction of Cooling Load Using Real Weather Data"

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NOMENCLATURE AND ABBREVIATIONS

a, represents design values for furnishings, air supply and return, type of fixture)

b, represents design values for room envelope construction (mass of floor area) and room air circulation and type of supply and return)

abvalues a and b values for cooling load factors when lights are on for 8, 10, 12, 14, 16 hours.

CLFaph sensible heat clf for hooded appliances

CLFapunh sensible heat clf for unhooded appliances

CLFGINSH cooling load factors for glass with interior shading

CLFLIT14 cooling load factors when lights are on for 14 hours

CLFPEOPL sensible heat cooling load factors for people

CLTDGCON cooling load temperature differences for conduction through glass

CLTDgconcorr cooling load temperature difference for conduction through glass corrected (adjustments for room temperature and outdoor daily average temperature)

days days of that particular year (365 days)

e east

egl east glass length

eglq east glass cooling load (Watts)

egw east glass width

ewlcltd east wall cooling load temperature difference

ewlcltdcorr east wall cooling load temperature difference corrected (adjustments for deviations of design and solar conditions

ewll east wall length

ewlq east wall cooling load (Watts)

ewlu east wall thermal conductance W/m^2 K

ewlw east wall width

Flm motor load factor

Fr fraction of the input energy of the hooded appliance released by radiation =0.32

Fsa fluorescent special allowance factor

Fu usage factor

Fum motor use factor

glarewl glass area east wall

glarnwl glass area north wall

glarswl glass area south wall

glarwwl glass area west wall

grarwwl gross area west wall

grsarewl gross area eastern wall

grsarnwl gross area north wall

grsarswl gross area south wall

gsv sensible heat gain from ventilation

hum relative humidity as hum%

Krf colour adjustment factor for roofs (=1 if dark coloured or light in an industrial area = 0.5 if permanently light-coloured (rural area))

Kw colour adjustment factors for dark coloured, light coloured in an industrial area or permanently light-coloured (rural area)

lat.h.g. latent heat gain / person

LMew latitude and month correction factor for cltd east wall

LMnw latitude and month correction factor for cltd north wall

LMrf latitude-month correction factor for cltd roofs

LMsw latitude and month correction factor for cltd south wall

LMww latitude and month correction factor for cltd west wall

m.efficiency motor efficiency

mnt minimum outdoor dry bulb temperature (°C)

month month of the same particular year (12 month)

mxt maximum outdoor dry bulb temperature (°C)

n north

netarewl net area east wall

netarnwl net area north wall

netarswl net area south wall

netarwwl net area west wall

ngl north glass length

nglq north glass cooling load (Watts)

ngw north glass width

nop number of people

nwcltdcorr north wall cooling load temperature difference corrected (adjustments for deviations of design and solar conditions

nwlcltd north wall cooling load temperature difference

nwll north wall length

nwlq north wall cooling load (Watts)

nwlw north wall width

patm atmospheric pressure (1013.25 mbar) 1.01325×10^5 Pa

pw actual partial pressure of water vapour (Pa)

pws saturation pressure of water vapour (Pa)

ql total latent heat gain from people

qla latent heat gain from appliances

Qlight heat gain from lights

qlv latent heat gain from ventilation (Watts)

qp heat gain from power

qs total sensible heat gain from people

qsa sensible heat gain from appliances

qse solar heat gain east glass

qsn solar heat gain north glass

qss solar heat gain south glass

qsv sensible heat gain from ventilation (Watts)

qsw solar heat gain west glass

rfarea roof area

rfcltd roof cooling load temperature difference

rfcltdcorr roof cooling load temperature difference corrected (adjustments for deviations of design and solar conditions

rfl roof length

rfq cooling load from roof (Watts)

rfu roof thermal conductance

rfw roof width

ROOFCLTD cooling load temperature difference for roofs

s south

SC shading coefficients (ratio of solar heat gain through a glazing system under a specific set of conditions to solar gain through a single light of the reference glass under the same conditions).

sens.h.g. sensible heat gain / people

sgll south glass length

sglq south glass cooling load (Watts)

sglw south glass width

SHGFew maximum solar heat gain factor for sunlit glass W/m^2 for east glass

SHGFnw maximum solar heat gain factor for sunlit glass W/m^2 for north glass

SHGFsw maximum solar heat gain factor for sunlit glass W/m^2 for south glass

SHGFww maximum solar heat gain factor for sunlit glass W/m^2 for west glass

swl south wall length

swlcltd south wall cooling load temperature difference

swlcltdcorr south wall cooling load temperature difference corrected (adjustments for deviations of design and solar conditions

swlq south wall cooling load (Watts)

swlw south wall width

time time of the day

toopho total operational hours for lighting or/ and (total hours in space for people)

TOTALQ Grand total heat gain (the sum of all elements or components of heat gain) to form the total cooling load.

tR indoor (room design temperature)

w specific humidity or (absolute humidity) expressed in kg water vapour/kg of dry air

w west

wgll west glass length

wglq west glass cooling load (Watts)

wgwl west glass width

wwlcltd west wall cooling load temperature difference

wwlcltdcorr west wall cooling load temperature difference corrected (adjustments for deviations of design and solar conditions

wwll west wall length

wwlq west wall cooling load (Watts)

wwlw west wall width

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CHAPTER I

INTRODUCTION

1.1 An Overview

The primary objective of this study is to provide a convenient, consistent, and accurate method of estimating cooling loads that enables the designer to select systems that meet the requirements for efficient energy utilisation. The developed programme provides data on the dynamic behaviour of the building and allows simulation to be made of its thermal performance. The novel aspect of this thesis is that past weather data is used for each day of the year and hourly changes of factors that affect the building cooling load are allowed for.

In this study, a method of building cooling load estimation has been developed, using real weather data to determine the time varying cooling load. The building's performance can be analysed and corrections can be made to the design in the early stages in order for the building to operate efficiently, leading to smaller cooling plant, less maintenance required, less capital cost, less energy consumption, and less environmental damages (global warming and ozone depletion). The overall scope of the study is better illustrated by a schematic diagram as shown in figure 1.1.

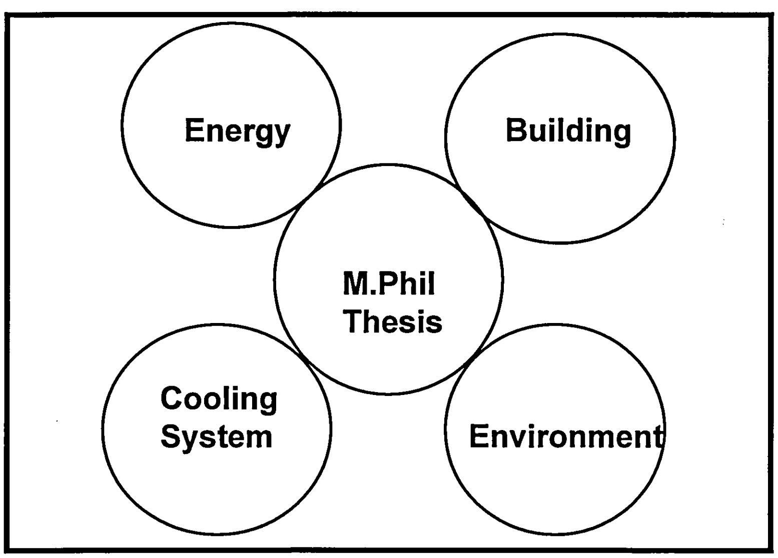

Figure 1.1 Schematic diagram indicating the scope of study

This study is the first stage of a broader project that will allow suppliers of district heating networks to provide cooling to buildings using absorption chillers.

District heating networks have been established in numerous cities through the world, particularly in the Scandinavian countries. Some cities also incorporate cooling circuits or district cooling [1]. An alternative to the cooling network is to use the district heating hot water to provide cooling by means of an absorption chiller.

A knowledge of the estimated loads using the model developed in this project will enable the designer to choose a suitable size of machine and will provide information for the suppliers of heat on the district heating network. A knowledge of the city wide heating load is necessary, especially if differential heat pricing is to be used in the summer months when excess heat is often available and particularly if the source of heat is from waste heat, for example incineration.

The methodology used in this study is the CLF/CLTD procedure of ASHRAE [2].

The Cooling Load Factor (CLF) and Cooling Load Temperature Difference (CLTD) is used by ASHRAE (American Society of Heating Refrigeration and Air-Conditioning Engineers) to allow for the thermal lag factors that occur due to the construction of the building and time of day. The use of these factors are highlighted in Appendix D.

Although ASHRAE has continually improved the accuracy of the load calculations procedure, many engineers and designers have found a need for a more detailed explanation of the procedure to go along with that increased technical accuracy. This explanation is given in chapter 3.

The cooling load obtained by the procedure described by ASHRAE GRP 158 [3] will generally agree within 5% of the results of the Transfer Function Method outlined in the 1977 ASHRAE Handbook of Fundamentals.

One note of caution: the ability to estimate loads more accurately due to changes in the calculation procedure provides a lessened margin of error. Therefore, it becomes increasingly important to survey and check more carefully the load sources, each item in the load, and the effects of system type on the load.

This tightening up on the hidden safety factors occurs for a number of reasons. There is greater emphasis, by standards and codes, on sizing equipment closer to the expected loads, as determined by outside design weather conditions at the 2.5% summer value and the 97.5% winter value.

Also, the suggested indoor design temperatures are now usually 78°F(25.5°C) for cooling and 72°F (22.22°C) for heating. These are the recommended ASHRAE design values but many National standards are different. Installed lighting levels are being reduced and the calculations are using lighting loads closer to the actual loads.

All of these factors require that the designer introduces any margin of safety by a positive action, rather than to rely on an assumed hidden margin.

1.2 The Purpose Of Load Calculations

Load calculations can be used to accomplish one or more of the following objectives:

1. Provide information for equipment selection and HVAC system design and capital cost.
2. Provide data for evaluation of the optimum possibilities for load reduction.

3. Permit analysis of partial loads as required for system design, operation and control.
4. Provide information on energy requirement and running cost.
5. Provide data for evaluation of the required maintenance and cost.

These objectives can be obtained not only by making accurate load calculations but also by understanding the basis for the loads.

1.3 Principles Of Cooling Loads Estimation

In air conditioning design there are three distinct but related heat flow rates, each of which varies with time:

1. Heat Gain or Loss
2. Cooling load or Heating load
3. Heat Extraction or Heat Addition Rate

Heat Gain, or perhaps more correctly, instantaneous rate of heat gain, is the rate at which heat enters or is generated within a space at a given instant of time. There are two ways that heat gains are classified. They are the manner in which heat enters the space and the type of heat gain.

The manner in which a load source enters a space is indicated as follows:

1. Solar radiation through transparent surfaces such as windows
2. Heat conduction through exterior walls and roofs
3. Heat conduction through interior partitions, ceiling and floors
4. Heat generated within the space by occupants, lights, appliances, equipment and process
5. Loads as a results of ventilation and infiltration of outdoor air
6. Other miscellaneous heat gains

The types of heat gain are sensible and latent. Proper selection of cooling and dehumidifying equipment is made by determining whether the heat gain is sensible or latent. Sensible heat gain is the direct addition of heat to an enclosure, apart from any change in the moisture content, by any or all of the mechanisms of conduction, convection and radiation. When moisture is added to the space for example by vapour emitted by the occupants, there is an energy quantity associated with that moisture which must be accounted for.

If a constant moisture content is to be maintained in the enclosure, then water vapour must be condensed out in the cooling apparatus at a rate equal to its rate of addition in the space. The amount of energy required to do this is essentially equal to the product of the rate of condensation per hour and the latent heat of condensation. This product is called the latent heat gain.

1.4 Thermal Control Concepts

Energy conservation should not be regarded as cutting back on comfort conditioning to the limit of what the occupants can bear. The technology is available for maintaining perfectly acceptable comfort conditions at energy consumption levels much lower than are currently experienced.

Sometimes, by taking advantage of innovative technology and new design concepts, and applying a measure of creativity and imagination, this can be accomplished at little or no additional cost, and in some cases, it may actually be less expensive. But first, some basic information is needed to creatively apply energy efficient innovations.

Since heat loss plays a crucial role in maintaining the body's thermal equilibrium, the physical principles of this interaction must be elaborated in order to provide a basis for designing an environment that satisfies the objectives of comfort and health.

1.5 Heating and Cooling Load

At any given time, if the sum of the gains equals the sum of the losses, then no mechanical heating or cooling is required. Otherwise, systems must be employed to actively add heat to or remove it from the space. Portions of the envelope may be designed, in some cases, with the ability to vary their transmission of heat, light, and air. Providing these necessities naturally, when available and desired, minimises the use of mechanical systems.

Time itself can have a great influence on thermal loads, since massive materials that are part of the envelope or contained within a space can absorb excess heat which will be released later. Temperature extremes are thus moderated, and by taking advantage of the cyclical nature of some loads, heat gains can be delayed by using thermal storage mass to offset heat losses at a later time. The net requirements for mechanical heating and cooling can sometimes be reduced or eliminated altogether in this way.

Since air contains moisture, it is imperative that cold spots below the dew-point temperature be avoided within the space or within the envelope construction, they can result in visible or concealed condensation. In general, the presence of water can cause swelling in all plant and animal fibres and in masonry materials, rotting of wood, rusting or corrosion of metals, damage to decorative finishes, and a weakening of products and materials that are not designed for contact with water. Solutions involve removing some of the humidity from the air, maintaining all visible surfaces above the dew point, and locating a vapour barrier on the warm, humid side of all insulation to block moisture from passing through to a cold surface and condensing where it is concealed.

Another moisture problem is too little humidity. Health and the maintenance of finishes and furnishings dictate at least a 20% RH. In order to maintain that, the envelope must have a certain minimum thermal resistance and, in particular, fenestration must be double glazed-in cold climates in order to avoid condensation.

1.6 Variations of Load

The heating and cooling loads on a building are dynamic, changing dramatically with occupancy and weather, both diurnal and seasonal. Unlike the ASHRAE guide which requires only one set of design outside weather conditions, the model developed allows for hourly variations in buildings usage and weather data for the whole heating and cooling season.

1.7 Thesis Structure

Chapter 2 Presents a method of predicting a building's cooling load using real weather data. The theoretical development of the program using CLTD/CLF method has been described because the scope of this thesis will capitalise on the advantage that can be derived from this technique. In addition, mathematical derivations on the cooling loads that were used such as statistical analysis. Also a basic foundation on Qbasic programming model is described in this chapter.

Chapter 3 Discusses the program results. All the output to the program has been illustrated in graphical form. A summary for selecting chillers using the above method using real weather data is also presented.

Chapter 4 Derives the conclusion from the research and discusses the achievement of research. A summary of findings and contribution to knowledge from the work done are presented in this chapter. Finally, this chapter presents several recommendation that can be pursued in the future.

CHAPTER 2

A NEW METHOD OF PREDICTING COOLING LOADS USING REAL WEATHER DATA

2.1 An Overview

A dynamic simulation model was developed to predict cooling load or (heat gain) as a function of dynamic environmental factors. The model has options to evaluate the effects of location, time of the year, orientation, glazing (single or double).

An analysis of the building energy consumption and behaviour can be made when the building orientation is changed.

This study describes a computer program which has been modelled to determine and predict daily cooling loads for a building using past daily real weather data. Knowing the daily cooling load will enable the designer to choose a suitable size of a cooling machine and the more efficient use of energy [4] and [5].

This program uses past real daily outdoor dry bulb temperature and a coincident moisture content which leads to real estimates for cooling loads.

While most publications and guides use one outdoor design dry bulb temperature and a coincident wet bulb temperature or moisture content for the whole summer season for the purpose of cooling load calculation which might lead to over or under size of a cooling equipment.

Yoshida and Terai, showed that daily change of weather is more important than a monthly or hourly change [6].

Also this program allows simulations to be made using different indoor design temperatures to predict how many degrees rise or drop of indoor temperature when using under or over size of cooling machine.

The objective of the study has been to develop a computer based tool for use by engineers when designing and selecting an air conditioning system.

2.2 Introduction

There are different models that can be used to determine the cooling loads of building. The more sophisticated models will allow for air temperature and solar gain. The methods considered for this study were the ASHRAE models and the CIBSE guide [36]. The ASHRAE CLTD/CLF method was chosen as it is an internationally recognised method and it was used by [21] in the PZYCHRO 2.0 computer package which has been used by the author for this study.

The cooling load calculations are usually based on indoor and outdoor design conditions of temperature and humidity. The inside conditions are those that provide satisfactory comfort. The outdoor summer design conditions are based on reasonable maximums using weather records. These values will normally be equalled or exceeded 2.5% of the summer time hours [7].

The dry bulb temperature and the coincident wet bulb temperature occurring at the same time are listed together in any climatic conditions tables and should be used as the corresponding design values.

The separate design wet bulb temperature does not usually occur at the same time as the dry bulb temperature and therefore should not be used in the load calculations.

Previous weather data tables showed this value, which if used, would result in too large design cooling load. The separate wet bulb temperature may be needed however, in selecting a cooling tower for special applications.

The 2.5% values supposed to provide a reasonable compromise between comfort and cost for most applications, and for different requirements 1% and 5% values can be found in the ASHRAE handbook tables.

As months for summer outdoor design temperatures in the northern hemisphere June, July, August and September can be used. Occasionally, maximum cooling loads occur in other months due to solar radiation, and therefore it is necessary to know the expected design conditions at those times.

The same thing applies to winter design conditions when calculating the heating loads where the value entitled 97.5% dry bulb temperature is the outdoor design air temperature most commonly used.

The 97.5% figure means that in an average winter, from December, January through February the outdoor temperature will be above the listed design value 97.5% of the time. In other words, the outdoor temperature will be below the design value 2.5% of the time. In theory, when the outdoor temperature drops below the design temperature, the indoor temperature should also drop below the indoor temperature because the heating system would be inadequate.

Although, this rarely occurs because the heating system usually has excess capacity, and there is heat storage in the building, as well as an allowable temperature differential associated with the heating system controls.

There are also 99% and 95% outdoor design temperature values for more and less critical applications. The advantage of using the 97.5% value instead of lower outdoor design temperatures (often used by designers in the past) is that it reduces oversizing of equipment, resulting in less costly systems, the equipment is run more steadily, increasing its life span, and energy use may be reduced.

During summer, the four warmest months, the maximum temperature usually occur between 2.00p.m. and 4.00p.m. suntime [8]. During the three coldest months of winter, the minimum temperature usually occur between 6.00 a.m. and 8.00 a.m. suntime.

The daily dry bulb variation will be of the order of the daily range stated on typical design days, however, statistically the daily range is the long term average daily range for only the warmest month.

The daily range is generally greater during clear weather and much less during cloudy weather or during precipitation. There are tables of maximum dry bulb and wet bulb temperatures but it should be noted that these values are not taken at the same time.

If the maximum dry and maximum wet bulb temperatures are assumed to be coincident this can result in weather oriented loads being calculated up to 1/3 greater than might otherwise be expected [8].

Some types of days that must be accommodated are more frequent in occurrence than maximum or minimum design days. Examples of these are cloudy, small temperature change , windy, warm a.m. and cool p.m., fair and warm, and fair and cool.

The dry bulb temperature presented in climatic conditions tables represent values which have equalled or exceeded by 1, 2.5, and 5% of the total hours during the summer months of June, July, August, and September (a total of 2928 hr) in the northern hemisphere and the months of December, January, February, and March in the southern hemisphere with a total hour count of 2904 hr.

In a normal summer, there would be approximately 30 hr at or above a 1% design value and approximately 150 hr at or above a 5% design value.
That means there would be some days the cooling machine is inadequate if it has not been oversized.

In order to examine the options in the design of a cooling machine the program allows simulations to be made using real weather data. The cooling loads for a building can be analysed and a suitable size of the machine can be chosen. Also the program is able to predict the rise in temperature when using a smaller size of machine.

The normal load estimating procedure has been to evaluate the instantaneous heat gain to a space and to assume that the equipment will remove the heat at this rate . Generally, it was found that the equipment selected on this basis was oversized and therefore capable of maintaining much lower room conditions than the original design [9]. Extensive analysis, research and testing have shown that the reasons for this are:

1. Storage of heat in the building structure.
2. Non simultaneous occurrence of the peak of the individual loads (diversity).
3. Stratification of heat, in some cases[10] and [11].

The program contains the data and procedures for determining the load when the equipment is actually picking up at any one time (actual cooling load), taking into account the factors 1 and 2 above. Application of these data to the appropriate individual heat gains results in the actual cooling load.

The actual cooling load is generally considerably below the peak total instantaneous heat gain, thus requiring smaller equipment to perform a specific job.

In addition, the air quantities and/or water quantities are reduced, resulting in smaller overall system.

Also, if the equipment is operated somewhat longer during the peak load periods, and/or the temperature in the space is allowed to rise a few degrees at the peak periods during cooling operation, a further reduction in required capacity results.

The smaller system operating for longer periods at times of peak load will produce a lower first cost to the customer with commensurate lower demand charges and lower operating costs.

It is well known fact that equipment sized to more nearly meet the requirement results in a more efficient, better operating system. Also, if a smaller system is selected, and is based on extended periods of operation at the peak load, it results in more economical and efficient system at a partially loaded condition.

As an example of how to overcome peak loads, when using a smaller size of cooling machine is precooling, using storage of heat in the building structure. This also applies to winter heating where house heat demand is a function of heat loss, internal gain, thermostatic setting, and thermal capacitance[12].

The building thermal capacitance affects the energy usage in two ways[13]. The first is that in a month with both high heating loads and high solar gains, excess energy is stored in the structure during daytime and released at night.

This reduces the auxiliary energy requirement over that for a building with no capacitance. The second effect is that energy stored in the structure allows the house temperature to drop slowly after the thermostat is turned down at night. This increases the auxiliary energy over that for a building with no capacitance.

2.3 Precooling As a Means of Increasing Storage

Precooling a space below the temperature normally desired increases the storage of heat at the time of peak load [14], only when the precooling temperature is maintained as the control point. This is because the potential temperature swing is increased, thus adding to the amount of heat stored at the time of peak load.

Where the space is precooled to a lower temperature and the control point is reset upward to a comfortable condition when the occupants arrive, no additional storage occurs. In this situation, the cooling unit shuts off and there is no cooling during the period of warming up.

When the cooling unit begins to supply cooling again, the cooling load is approximately up to the point it would have been without any precooling.

Precooling is very useful in reducing the cooling load in applications such as churches, supermarkets, theatres, where the precooled temperature can be maintained as the control point and the temperature swing increased to 4.4 or 5.6°K (8-10°F).

Before the load can be estimated, it is imperative that a comprehensive survey be made to assure accurate evaluation of the load components. If the building facilities and the actual instantaneous load within a given mass of the building are carefully studied, an economical equipment selection and system design can result in, trouble free performance. The heat gain or loss is the amount of heat instantaneously coming into or going out of the space. The actual load is defined as that amount of heat which is instantaneously added or removed by the equipment.

The instantaneous heat gain and the actual load on the equipment will rarely be equal, because of the thermal inertia or storage effect of the building structures surrounding a condition space. Applying storage factors to the appropriate heat gains result in the actual load.

The factor CLF accounts for storage of part of the component heat gain, for example lighting. The storage effect depends on how long the lights and cooling system are operating, as well as the building construction, type of lighting fixture, and ventilation rate.

2.4 Cooling Load Estimation

The air conditioning load is estimated to provide the basis for selecting the conditioning equipment. It must take into account the heat coming into the space from outdoors on a design day, as well as the heat being generated within the space. A design day is defined as:

1. A day on which the dry and wet bulb temperature are peaking simultaneously.
2. A day when there is little or no haze in the air to reduce the solar heat.
3. All of the internal loads are normal.

The time of peak load can usually be established by inspection, although in some cases, estimates must be made for several different times of the day.

Actually, the situation of having all of the loads peaking at the same time will very rarely occur. To be realistic, various diversity factors must be applied to some of the load components.

The sources of heat gains that form the cooling load are outdoors loads and internal loads.

2.4.1 Outdoors Loads

The outdoor loads are the portion of the load on the air conditioning equipment that originates outside the space and they consist of:

1. The sun rays entering windows: The solar heat gain is usually reduced by means of shading devices on the inside or out side of the windows. In addition to this reduction, all or part of the window may be shaded by reveals, overhangs, and by adjacent buildings.

A large portion of the solar heat gain is radiant and will be partially stored. It is normal practice to apply storage factors to peak solar heat gains, in order to arrive at the actual cooling load imposed on the air conditioning equipment.

2. The sun rays striking the walls and roof: These, in conjunction with the high outdoor air temperature, cause heat to flow into the space. The cooling load temperature difference used to estimate the heat flow through these structures.

3. The air temperature outside the conditioned space: A higher ambient temperature causes heat to flow through the windows, partitions, and floors. The temperature differences used to estimate the heat flow through these structures.

4. The wind blowing against a side of the building: Wind causes the outdoor air that is higher in temperature and moisture content to infiltrate through the cracks around the doors and windows, resulting in localised sensible and latent heat gains. All or part of this infiltration may be offset by air introduced through the apparatus for ventilation purposes.

5. Outdoor air usually required for ventilation purposes: Outdoor air is usually necessary to flush out the space and keep the odour level down. This ventilation air imposes a cooling and dehumidifying load on the apparatus because the heat and/or moisture must be removed. Most air conditioning equipment permits some outdoor air to bypass the cooling surface.

This bypass outdoor air becomes a load within the conditioned space, similar to infiltration; instead of coming through a crack around the window, it enters the room through the supply air duct. The amount of bypassed outdoor air depends on the type of equipment used and the requirements for comfort applications.

2.4.2 Internal Loads

The heat gain from any component that generates heat within the conditioned space is known to be Internal load and it is the other portion of cooling load imposed on the air conditioning equipment.

The internal load, or heat generated within the space, depends on the character of the application. Proper diversity factor and usage factor should be applied to all internal loads. As with the solar heat gain, some of the internal gains consist of radiant heat which is partially stored, thus reducing the load to be imposed on the air conditioning equipment.

Internal heat gains consist of:

1. People: The human body through metabolism generates heat within itself and release it by radiation, convection, and evaporation from the surface, and by convection and evaporation in the respiratory tract. The amount of heat generated and released depends on surrounding temperature and on the activity level of the person.

2. Lights: Illuminants convert electrical power into light and heat. Some of the heat is radiant and is partially stored.

3. Appliances: Restaurants, hospitals, laboratories, and some speciality shops (beauty shops) have electrical, gas, or steam appliances which release heat into the space. The amount of heat gain when using not hooded appliances can be reduced if a positive exhaust hood is used.

4. Electric machines: To evaluate the heat gain from electric machines we have to refer to manufacturer's data. Normally, not all of the machines would be in use simultaneously, and therefore a usage or diversity factor should be applied to the full load heat gain. The machines may also be hooded, or partially cooled internally, to reduce the load on the air conditioning system.

5. Electric motors: Electric motors are a significant load in industrial applications and should be thoroughly analysed with respect to operating time and capacity before estimating the load.

6. Hot pipes and tanks: Steam or hot water pipes running through the air conditioned space, or hot water tanks in the space, add heat. In many industrial application, tanks are open to the air, causing water to evaporate into the space.

7. Miscellaneous sources: There may be other sources of heat and moisture gain within a space, such as escaping steam (industrial cleaning devices, pressing machines), release of absorbed water by hygroscopic materials (paper, textiles).

In addition to the heat gains from the indoor and outdoor sources, the air conditioning equipment and duct system gain or lose heat. The fans and pumps required to distribute the air or water through the system add heat.

Heat is also added to supply and return air ducts running through warmer or hot spaces. Cold air may leak out of the supply duct and hot air may leak into the return duct. The procedure for estimating the heat gains from these sources is the percentage of room sensible load, room latent load, and grand total heat load.

The barometric or atmospheric pressure needs to be taken account of in the selection of air conditioning systems. The international standard adopted is 101325 Pa, which is the mean value at sea level and 45° N latitude [15].

The psychrometric chart shows the relationship between the amount of water vapour in the atmosphere and the temperature and other properties of the mixture, as various processes are carried out by an air conditioning system.

The values of the relevant properties and the way in which they change during a process is different if the barometric pressure alters. However, the changes of barometric pressure within the UK, due to variations in the weather and the altitude above sea level, are about plus or minus 5% and are not sufficient to warrant using other than a standard chart.

For work overseas (outside Britain), where altitude may be much above sea level, a chart for the local barometric pressure must be used. In the case of the computer model used the local barometric pressure can be input as a variable.

Also there are practical considerations when choosing a design supply air temperature :

1. The lowest safe air temperature possible from an air cooler coil.
2. The contact factor of the coil.
3. The rise in temperature from fan power and duct heat gain.

In addition to that the quantity of supplied air is an important factor that effects choosing the system as been found by Herzig and Wajcs [16], where they showed that the lower air quantity caused a longer heating cycle.

2.5 Building Survey and Space Characteristics

Building survey is an important factor that should be given attention when designing an air conditioning system, an accurate survey of the load components of the space to be air- conditioned is a basic requirement to determine a realistic cooling and heating loads. The completeness and accuracy of this survey is the very foundation of the estimate. Mechanical and architectural drawings, complete field sketches and, in some cases, photographs of important aspects are part of a good survey. The following aspects should taken into account:

1. Orientation of the building - Location of the space to be air conditioned with respect to:
   a) Compass points - sun and winds effects.
   b) Nearby permanent structures - shading effects.
   c) Reflective surfaces - water ,sand, car parks, etc.

2. Use of space - office, hospital, factory, assembly plant, etc.

3. Physical dimensions of space - Length, width, and height.

4. Ceiling height - Floor to floor height, floor to ceiling, clearance between suspended ceiling and beams.

5. Construction materials and thickness of walls, roof, ceiling, floors and partitions, and their relative position in the structure.

6. Surrounding conditions - exterior colour of walls and roof, shaded by adjacent building or sunlit. Attic spaces - unvented or vented, gravity or forced ventilation. Surrounding spaces conditioned or unconditioned adjacent spaces, such as boiler room, and kitchens. Floor on ground, crawl space, and basement.

7. Windows - Size and location, wood or metal sash, single or double hung. Type of glass single or multipane. Type of shading device. Dimensions of reveals and overhangs.

8. Doors - Location, type, size, and frequency of use.

9. Stairways, lifts, and escalators - Location, temperature of space if open to unconditioned area. Power of machinery, ventilated or not.

10. Thermal storage - Includes system operating schedule (12, 16 or 24 hours per day) specifically during peak outdoor conditions, permissible temperature swing in space during a design day, rugs on floor, nature of surface materials enclosing the space.

11. Continuous or intermittent operation - Whether system be required to operate every business day during cooling season, or only occasionally, such as churches and ballrooms. If intermittent operation, duration of time available for precooling or pulldown has to be determined.

2.6 Program Characteristics and Calculation Procedure

This computer program which has been modelled to determine and predict daily cooling loads for a building, is based on full year (365 days) past daily real weather data as input. The program repeats the daily cooling load calculations over a year.

2.6.1 Methodology

The computer program is written in Qbasic [17], [18],[19] and the CLTD/CLF method [2[, [20] and [Appendix D] is used to estimate building cooling loads. Pzychro 2.0 is used to obtain some of the thermal resistance of the walls and psychrometric air properties [21]. The computer program was written so that the cooling load could be calculated at any time of the day and the year, in addition to a minimum and maximum cooling load. The flowchart has been drawn in Appendix E using reference [22].

2.6.2 Assumptions

The developed program has used assumed values for each of the fixed parameters in the equations. These values can be changed each time we run the program.

The building dimensions for the model used can be changed by editing the building dimensions field in the program. The assumed parameters consist of:

1. U Conductance value for walls.
2. U Conductance value for roof.
3. The program used the CLTD for flat roofs only.
4. U Conductance value for glass.
5. Sc Shading coefficient value for glass.
6. Number of people.
7. Lights (w)
8. Fixture type (light).
9. Power (heat gain)
10. Appliances (heat gain).
11. Ventilation L/S
12. Building orientation.
13. Wind velocity.
14. Outdoor design temperature.
15. Infiltration (Crack method).
16. Indoor design temperature (15-30 °C).
17. Outdoor design temperature (°C) from Meteorological office.
18. W_{in} Specific humidity (or humidity ratio) kg moisture/kg dry air.

19. W_{out} Specific humidity (or humidity ratio) kg moisture/kg dry air or RH% from the Meteorological Office.
20. Design indoor temperature (°C)

2.6.3 Program limits and factors taken into account

The program limits could be summarised as:

Some of the results in this study represents the effects of the dynamic environmental factors which consist of :

1. Past weather data collected from the Meteorological office.
2. Latitude of the building which is being designed.
3. Orientation of the building.
4. Location of the building due the relative rotation of earth and sun (Solar cooling load as a function of time of day).
5. The required room design temperature.

2.6.4 In addition to that the model takes into account the effects of :

1. Roof type
2. Walls type
3. Operational hours of lighting (start time and duration of operation of lights and equipment)
4. Time elapsed since entering the building (start time and duration of occupancy)
5. Types of windows
6. Type of furnishing, heavyweight, ordinary, with carpet or without etc.
7. Air supply and return and type of light fixture.
8. Mass of floor area (wood, concrete kg/m^2) etc.
9. Time of the day. (The program is able to evaluate cooling load of a

specified building at any time of the 24 hours of the day, also able to get the minimum and maximum).

2.6.5 The Factors That Has Not Been Taken Into Account By The Program

The program does not take the following factors into account:

1. Cooling load due to fan motor temperature increase.
2. Cooling load due to duct conduction.
3. The assumption of sea level pressure and elevation is reasonable up to about (2500 ft) 760 metres elevation at which there will be a 10% error in the cooling load calculation.
4. Coil cooling load.
5. Duct air leakage (used as % of total cooling load).
6. Cloudy day or precipitation and it assumes clear sky calculation regarding the solar load.
7. Building having over hang or fins.
8. Recess or reveal in the windows.
9. the model does not allow for the large variations in occupancy that actually occur during the week and throughout the seasons.

2.7 Program Input

Input data: Input data are of two types in the program:

1. Options data: Which represents the options that are given to the designer prior to running the program also they represent its limits. They are mentioned under the program limits:

2. Weather data: They are the real weather data that have been taken by the meteorological office from their own monitoring stations nation wide.

These real weather data are in the form of daily minimum dry bulb temperature, maximum dry bulb temperature, relative humidity, and dry bulb temperature when the relative humidity was being taken.

2.7.1 Evaluation of Cooling Load: Building Locations

CITY	YEAR	LATITUDE	LONGITUDE
BRISTOL	1986	51.27 N	2.35 W
DYCE	1986	57.12 N	2.11 W
HULL	1986	53.45 N	0.20 W
LONDON	1986	51.30 N	0.10 W
LEEDS	1986	53.50 N	1.35 W
EAST KILBRIDE	1986	55.46 N	4.10 W
SHEFFIELD	1986	53.23 N	1.3 W
SHEFFIELD	1988	53.23 N	1.3 W
ERIE (USA)	1988	42.15 N	81.00 W

[23],[24],[25]

2.8 Data Processing

The input data has to be processed in order to match the requirement of the relevant equations. Therefore the relative humidity has to be changed to the form of moisture content (specific humidity).

2.9 Program Output

Output data: The output to the program can be either daily grand total cooling load, total sensible, total latent cooling loads, or each component that contributed individually in the grand total cooling load over 365 days of the year.

In addition to the above, the program can add any of the input data as output, for example, the maximum dry bulb temperature and specific humidity. We are also able to get the cooling loads at any hour of the day as well as the maximum and minimum cooling loads.

The program is able to calculate the cooling load after a certain time of lights operation or/and people attendance has elapsed, also the cooling load can be estimated after determining the type of furnishing, the mass of floor area, roof type, latitude, and indoor design temperature . The program can be run with any of seven types of walls.

The program can be loaded and run in Qbasic, the load and running times being in the matter of seconds on a typical 486 PC. The output is in the form of data file which can be used with Spreadsheets (Excel) to produce output in a graphical form. The computer program's integrity was validated by comparing the Qbasic equations of each section with a manual set of calculated values (Appendix G).

2.13 Summary

In this chapter a new method of cooling load calculations is presented. The advantages and limitations of using this method are also identified.

Results from the program showed that past real weather data could be used to predict patterns of cooling loads.

Analysing each of the components that contributed to the total cooling load could be used to rectify the design of the building and avoid any excess in the cooling load which would lead to a reduced size of machine.

Moreover the same results could be used to predict for capital cost, selection of cooling machine and planned maintenance.

CHAPTER 3

DISCUSSION OF THE PROGRAM AND RESULTS

3.1 Discussion

The program allows the designer to determine the cooling loads for each of the 23 components. By analysing each of the components the designer can highlight any significant load and take appropriate action.

Methods of cooling load reduction are given in Appendix F. This reviews information from a number of sources given in the bibliography or referenced in the text.

Figure 1 shows a comparison between the energy required to cool the specified building in Sheffield 1988 using different indoor design temperatures.

Designing a cooling load for the building using inside design temperature of 21°C, requires more energy to cool, compared to 24 and 27°C. The higher energy requirement will result in a larger size of cooling machine which will cause increased cycling when operating on part load. It can be seen that when cooling to 21°C as room design temperature a 600 kW machine is only required twice a year.

Figures 2,3,4,5,6,7,8,9 and 10 represent the grand total cooling loads for Erie 1988, Bristol 1986, Dyce 1986, London 1986, Leeds 1986, Sheffield 1986, East Kilbride 1986, Hull 1986 and Sheffield 1988 for a design temperature of 24° C.

Since temperature and humidity condition vary throughout the world due to geographical area and general weather movements, the cooling loads will vary accordingly.

In the case of the United Kingdom (1986) there is a correlation between the peaks and troughs, can be seen. This is because the UK weather is dominated by fronts crossing the country from the Atlantic. These quickly cross the country and change the dry bulb temperature and absolute humidity of the outside air.

Differences between the loads can be explained by the local conditions, dry bulb temperature, absolute humidity, latitude and rain fall which have an effect on the micro-climate of the region. It is also seen that the micro climate has a great effect on the cooling load. Where size of cooling machine will be selected for each city for the same building.

Comparing weather data for different years of the UK (1986, 1988) a similar pattern can be seen in the season, but no correlation between the peaks and troughs.

Comparing the 9 graphs, an increase in maximum cooling load in each city can be seen, and the period required for cooling, using the same building specifications.

The maximum cooling load are 800 kW in Erie, nominally 600 kW in Bristol, 450 kW in Dyce, 600 kW in London, 550 kW in Leeds, 550 kW in Sheffield 1986, 450 kW in East Kilbride, 600 kW in Hull, and 480 kW in Sheffield 1988.

The tediousness of the repetitive calculations for working out cooling loads can deter designers from attempting detailed load profiling and this can result inaccurate estimates. This program repeats the lengthy calculations 365 times and changes can be made for any of the factors and repeat the calculations again in order to design and get the best performance of the building taking into account the energy consumption and the capital cost of the building.

Figure 11 represents total cooling loads for different latitudes 40,48,56 using Sheffield 1988 weather data. Users of standards buildings (eg. Supermarkets) can use this information to compare sites throughout the country. This information can also be used by designers to determine the savings in cooling cost for an investment in improving the envelope structure.

Figure 12 represents cooling loads for the roof component only using the same type of roof in Erie, USA 1988 at different latitudes 40,48,56 while maintaining Erie's weather data. The graph shows the limits of the program when moving from latitude 40-48-56. And that is represented in the SHGF, walls and roofs CLTDs because they are a function of latitude.

There are 26 types of roofs, all included in the program, that can be changed every time we run it in order to reach at the optimum selection for roof material get the heat gain from roofs as shown in the figure. A comparison can be made between the energy savings and any extra investment in roof construction.

The roofs heat gain depends on the month, time of day, latitude, in addition to the outdoor average temperature.

The curves shows that while going from latitude 56 to 40 degrees north the energy requirement is increased to keep the same room temperature, particularly when looking above 171 days which shows that cooling loads are increased as we go to a lower latitudes.

Figure 13 represents the cooling load for the conduction load component through glass at the same building in Sheffield 1988, using the same area of glass and same type (same U value).

Because of using the same area and same type of glass, the curves are overlapping, i.e. the cooling load are equal and that shows how cooling loads for conduction through glass is a function of the area. Also a higher design temperature has been used 24°C which explains why the graph was in the negative region of the axis (max. temperature did not exceed 24°C).

Figure 14 represents the maximum cooling load for walls at a specified building in Sheffield 1988, using a building with equal sides areas (square) i.e. equal walls area and using the same material.

From the chart its very clear that the load profile for the northern wall (blue curve) is lower than that for south, west and east. And that walls start to exert a cooling load after the region (120-307) days, in the summer. And the west wall (yellow curve) has a higher cooling load value in June and July, while the south wall (the pink curve) has a higher value in August and October, and attention should be paid to those walls specially in summer. A room design temperature of 24°C has been used.

Figure 15 shows the variation for latent and sensible cooling loads for ventilation through the year in a specified building in Sheffield 1988 and how it can contribute to the grand total cooling load of the building. A room design temperature of 24°C and relative humidity of 50% have been used. This shows that on some days there can be a considerable peak in latent heat load.

Figure 16 represents the maximum solar cooling load for a specified building in Sheffield. From the chart, the maximum cooling load will come from eastern and western glasses, and this is clear from the yellow and navy blue curves especially the period between 151-241 days.

While the pink curve shows that maximum cooling load from the south glass will be in January, February, March, September, October, November and December.

The bottom curve (blue) represents cooling load from the northern glass and it has the lowest value compared to the west, east and south glasses. That is why the designer has to give more attention to those sides than the north one regarding shading and the size of windows areas. Looking at the east and west data there are two anomalies. For May and September the solar gain drops considerably. This can not be explained rationally; It is not due to a programming error as it is derived from the solar heat gain factor (SHGF) data tabulated from the ASHRAE Handbook [2]. The data itself has this anomaly.

Figures 17 and 18 represent the maximum solar cooling load for a specified building in London 1986 using two different latitudes 40 and 56 degree north. A graph like these is good indication how solar heat will be different from different latitudes. Where a comparison can be made between the energy savings and any extra investment in glass and shading type.

Figure 19 shows how the size of the machine increases with a decrease in room design temperature.

That could range from 750 kW when room design temperature is 18°C to 400 kW if 30°C has been taken as indoor design temperature.

A graph like this is a good tool to forecast the rise in indoor temperature when the machine will be off design if a smaller size is to be selected.

Also interpolation (modelling) can be made to predict temperature rise when using different size of machines. Simulation can be made in order to reach at the best options.

Early figures (2-10) showed loads for individual cities. Figure 20 represents a comparison between three different cooling loads (Bristol, Dyce, and London at Latitudes 48, 48, and 58 degree North) imposed by the same building when different weather data and different latitudes are applied in the model. That also shows how the weather plays a main roll in the building load, which will affect the size of the cooling machine

Also the graph shows how the maritime climate of the UK is affecting the building load. Difference in magnitudes can be seen in the loads, but there is a strong correlation between the peaks and the troughs.

Figure 21 shows the hourly version for a building cooling load based on two different indoor design temperatures of 21 and 30 °C.

A graph like this is a very simple and useful tool and will give a good indication of how many hours will be off design when using a smaller machine, where other strategies can be considered.

If for example the cooling load was calculated using the day-ahead weather forecast showed that the maximum cooling load was greater than the installed cooling capacities the building could be precooled overnight to reduce the daytime peak.

Figure 22 shows three components for the cooling load. Whenever the building is outside specification these graphs and any other components can be looked at to identify which components are significant. Then the designer could look to methods to identify load reduction [Appendix F].

Electricity cost vary considerably as the " pool ", figure 23. The concept of precooling can also be applied to provide cooling at night at low cost and to reduce the cooling when the prices are high. In this case it would be necessary to use both the day-ahead weather forecast and the day-ahead pool prices. Also same principle applies to ice thermal storage.

3.2 Summary

The cooling load calculation and using it to size and select the cooling machine is an economically viable energy conserving technology.

The benefits reaped by all parties concerned can be considerable, although the extent to which building users benefit, is primarily dictated by the tariff structure of the electricity supply companies or gas supply companies or the supplier of the heat source for example (Sheffield Heat and Power), the benefits are as follows:

3.2.1 To The Environment

1. Conservation of fossil fuels, by choosing a more suitable size of cooling plant so reducing design-point margins which will lead to more energy efficient and reliable systems, and by switching to another type of energy source, when using absorption chillers i.e. waste heat.
2. Reductions in carbon dioxide emissions (less pollution) [26].
3. Reductions in CFC emissions
4. Less global warming by the means of better use of the waste heat from the generating plant, less power plants are required and decommissioning the old inefficient generating plant.

3.2.2 To The Building User

1. Reduced chillers sizes
2. More efficient running of chiller plant
3. Likelihood of capital cost savings when compared to a larger chiller capacity for the same building cooling load
4. Substantial running cost savings when compared to a larger chiller capacity for the same building cooling load

3.2.3 To the electricity generating company

1. Load shifting when using a combination for example absorption and centrifugal chillers which will lead to a more efficient use of the power stations
2. It will enable to decommission old inefficient generating plant

CHAPTER 4

CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

4.1 Conclusion

A novel method of estimating the cooling load using past weather data has been successfully developed in this study. The research project extends current knowledge and a working model has been produced to size the cooling plant involved.

Calculating building cooling loads with this new method gives real amplitudes for each of the components taking into account the effect of outdoor loads and the simultaneous actual internal loads.

The program can be used when designing ice thermal storage systems, especially to study when to implement load shifting during periods of maximum demand. An early estimation of the hourly based cooling load of this new method has been made as output of the developed program and been utilised successfully as input to conduct further investigation of ice thermal storage systems [34] using the same building.

The twin pressures of market forces and the environmental lobby, will ensure in future years that the electricity utility companies will be keen to load balance, as it means they can decommission old inefficient plant and reduce the need to construct new generating capacity. The model developed can be used to shift the maximum demand when there are high electrical tariffs.

The model can be used for any location provided weather data is available for that latitude. This is particularly useful for extreme unpredictable climates, where the usual case is to install oversized machines.

The traditional method uses one pair of design temperature and humidity. Often these values will apply to a large geographical area. The new method has shown that there are different levels of cooling requirements for locations less than 100 kilometres apart.

Analysis of the results from the program showed that on days of peak loads other strategies like precooling could be used. The simulation also allowed the prediction of temperature rise when using smaller machines.

Analysis from the results showing each of the components of the grand total could be used to rectify any bad design causing high cooling loads for example orientation of the building especially in the early stage of the design, or even after design has been made using louvers for example.

The traditional method gives no indication of the changes in the cooling loads. It only provides a single maximum load. The new method gives the values for all variations of the input weather data.

The computer model described in this project is an attempt to produce a practical software tool which can be used by a designer for the benefit of the consumer and the electricity utility companies. This method is successfully utilised in the study for the following tasks:

1- To find out maximum cooling loads, its sources, and how to reduce them by doing some modification in the design in the early stage.

2- To develop a computer program which will be used by designers to size a building air conditioning systems and to see whether it can cope with the peak summertime cooling load of the building.

3- To perform multiscale analysis of a cooling load using its components to avoid high loads at peak time.

4- Using this program to predict the energy consumption and running costs when using different types of cooling machines based on a time of day tariff structure, also it can determine the daily running cost saving achieved when compared with a different type of air conditioning systems.

5- Using the program to select the size and type of machines which will lead to the selection of the fuel required and comparisons between renewable and non-renewable energy resources. In the case of cities like Sheffield there is a choice between fossil fuel powered chillers and absorption chillers using renewable heat from incineration.

6- To select important features that represents a cooling load.

This piece of program developed in this study is capable of identifying the peak cooling load and the size of cooling machine quickly and consistently. This is achieved by incorporating programming in the CLTD/CLF method. Results from the program show that in a worst scenario when the cooling load is peaking, how many hours will be off design.

A simulation could be made regarding any changes in the variables as well as the effects of those changes to be viewed in a graphical form. The designers is then able to examine reduction techniques as outlined in Appendix F. Payback periods can be estimated if the cost of changes in the building specification are known as the programme can determine the energy consumption and hence knowing the tariffs the energy savings can be determined.

The computer program is designed to be a general tool, by which systems designers can match any refrigeration chiller with any building cooling system. It is not specific to any one building or chiller manufacturer.

Although only a simple model for a building has been used in this study, this method could be extended to calculate more complicated designs. The steps required for calculating the building cooling loads in this method are much easier to carry out than the steps required for manual calculation.

4.2 Contributions to the field of energy and environment conservation.

Knowing the daily cooling load will enable the designer to choose a more suitable size of a cooling machine so reducing design-point margins which will lead to more energy efficient and reliable systems.

This method can also be incorporated into maintenance programmes for cooling plants, by using smaller machines the cycling of the machines can be reduced when working on part load.

The use of real weather data allows a designer to see typical patterns of plant usage. In many applications different types of cooling machines will be suitable and it will be necessary to compare capital cost, running cost, reliability, maintainability and the side effects on the environment regarding the global warming, green house gases and the ozone layer in addition to the relation with renewable and non-renewable energy.

4.3 Suggestions for future work

Real weather data can be incorporated with other cooling loads calculation methods to compare applicability, for example the ASHRAE transfer function method, time averaging method, and two recent methods, the radiant time series and the heat balance method. It has shown from this study that the calculation of cooling loads using real weather data was superior to the traditional method. Further developments would focus on a comparison between the various methods of estimating building cooling loads.

Artificial neural network algorithms can be applied to the numerous variables encountered in the model used. The computer model developed here lends itself to further studies in this area.

An upgrading of the programme is suggested for future work to increase its limits.

Data from a building management system could be compared with the programme's output. A suitable project would be to data log the chiller plant in the Sheaf building so that comparisons can be made.

The work considered here was to determine cooling loads but the model can also be used with some modifications to predict heating loads.

As stated in the introduction this study is part of a broader project to determine loads on a district heating network when absorption chillers are used. The next two stages are to look at the design of the chillers to meet the predicted loads and then to determine the heating loads required to drive the absorption chillers.

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Appendix A

Cooling Load Calculation Program

```
    ************************************************************************************

'Programm to start in Qbasic
     DIM mnt(370), mxt(370), t(370), hum(370), pws(370), pw(370), w(370), Todave(370)
     DIM qlv(370), qsv(370), TOTALQ(370), days(370), month(370), rfcltdcorr(370)
     DIM LMrf(370), nwlcltdcorr(370), ewlcltdcorr(370), swlcltdcorr(370)
     DIM wwlcltdcorr(370), CLTDgconcorr(370), rfq(370), eglq(370), ewlq(370)
     DIM sglq(370), swlq(370), wglq(370), wwlq(370), nglq(370), nwlq(370), qsinf(370), qlinf(370)
     'DIM qsinf(370), qlinf(370)
     DIM dw(370), Tout(370), Tamb(370)
      OPEN "c:\firas\dyce86.DAT" FOR INPUT AS #10
      OPEN "a:\dyce86W.DAT" FOR OUTPUT AS #2

     'LPRINT "Day", "TOTALQ", "MAX TEMP", "MOISTURE"
     'LPRINT " ", "W", "DEGREE C", "KG/KG AIR"
'SUB*************************************************************************

   INPUT "input time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time
   INPUT "toopho 1,2,3,4,5,6,7,8,9"; toopho
   INPUT "abvalues 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16"; abvalues
   INPUT "rooftype 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; rooftype
   INPUT "input latitude 40,48,56"; latitude
   INPUT "input tR 15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30"; tR

   '3**********************        ******************

IF tR = 15 THEN designw = .0053
IF tR = 16 THEN designw = .00565
IF tR = 17 THEN designw = .006033
IF tR = 18 THEN designw = .006433
IF tR = 19 THEN designw = .00685
IF tR = 20 THEN designw = .007283
IF tR = 21 THEN designw = .00775
IF tR = 22 THEN designw = .00825
IF tR = 23 THEN designw = .008767
IF tR = 24 THEN designw = .009317
IF tR = 25 THEN designw = .0099
IF tR = 26 THEN designw = .010517
IF tR = 27 THEN designw = .011167
IF tR = 28 THEN designw = .01185
IF tR = 29 THEN designw = .012567
IF tR = 30 THEN designw = .013317

  'LPRINT designw

  '4*********************        ******************
       OPEN "a:CLFGINSH.DAT" FOR INPUT AS #4

     ' clf for glass with interior shading (All Room Construction).

     'orientation 1=N , 2=NNE, 3=NE, 4=ENE, 5=E, 6=ESE, 7=SE, 8=SSE
     '  9=S, 10=SSW ,11=SW, 12=WSW, 13=W, 14=WNW,15=NW,16=,NNW,17=HOR
     'time of day  1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25=min,26=max
       'DIM CLFGINSH#(orientation, time)
```

```
DIM CLFGINSH#(1 TO 17, 1 TO 26)
 FOR j = 1 TO 17
   FOR k = 1 TO 26
     INPUT #4, CLFGINSH#(j, k)
    NEXT
  NEXT
 ' CLOSE #4

' INPUT "input time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time

PRINT "CLFGINSHn"; CLFGINSH#(1, time)
  PRINT "CLFGINSHe"; CLFGINSH#(5, time)
    PRINT "CLFGINSHs"; CLFGINSH#(9, time)
    PRINT "CLFGINSHw"; CLFGINSH#(13, time)

CLFGINSHn = CLFGINSH#(1, time)
  CLFGINSHe = CLFGINSH#(5, time)
    CLFGINSHs = CLFGINSH#(9, time)
      CLFGINSHw = CLFGINSH#(13, time)

'5**********************          ******************
    OPEN "a:CLFPEOPL.dat" FOR INPUT AS #5

    'sensible heat cooling load factors CLF for people

    'dim clf#(toopho,time)
    'total hours in space 1=2hrs, 2=4hrs,3=6hrs,4=8hrs,5=10hrs,6=12hrs,7=14hrs
    ' 8=16hrs,9=18hrs
    'time  1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25=min,26=max
    DIM CLFPEOPL#(1 TO 9, 1 TO 26)

      FOR j = 1 TO 9
       FOR k = 1 TO 26
        INPUT #5, CLFPEOPL#(j, k)
       NEXT
      NEXT
      CLOSE #5
    '  INPUT "toopho 1,2,3,4,5,6,7,8,9"; toopho
    ' INPUT "time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time

     PRINT "CLFPEOPL"; CLFPEOPL#(toopho, time)
     CLFPEOPL = CLFPEOPL#(toopho, time)

'6******************          *******************


    OPEN "a:CLFLIT14.dat" FOR INPUT AS #6
    ' cooling load factors when lights are on for 14 hours table 46 page 26.45


    'DIM CLFLIT14#(abvalues,time)
    'abvalues 1=.45A,
2=.45B,3=.45C,4=.45D,5=.55A,6=.55B,7=.55C,8=.55D,9=.65A,10=.65B,11=.65C,12=.65D,13=.75A,14
=.75B,15=.75C,16=.75D

    'time  1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25=min,26=max
     DIM CLFLIT14#(1 TO 16, 1 TO 26)
      FOR j = 1 TO 16
        FOR k = 1 TO 26
```

```
    INPUT #6, CLFLIT14#(j, k)
   NEXT
  NEXT
  CLOSE #6
' INPUT "abvalues 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16"; abvalues
' INPUT "time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time
 PRINT "CLFLIT14"; CLFLIT14#(abvalues, time)
 CLFLIT14 = CLFLIT14#(abvalues, time)

'7*****************          ***********************
 OPEN "a:CLFaph.dat" FOR INPUT AS #7
 'sensible heat clf for appliances-hooded table 48

 'dim clf#(toopho,time)
 'total operational hours 1=2hrs, 2=4hrs,3=6hrs,4=8hrs,5=10hrs,6=12hrs,7=14hrs
 ' 8=16hrs,9=18hrs
 'time  1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25=min,26=max
 DIM CLFaph#(1 TO 9, 1 TO 26)
   FOR j = 1 TO 9
    FOR k = 1 TO 26
     INPUT #7, CLFaph#(j, k)
    NEXT
   NEXT
   CLOSE #7
' INPUT "toopho 1,2,3,4,5,6,7,8,9"; toopho
' INPUT "time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time
 PRINT "CLFaph"; CLFaph#(toopho, time)
 CLFaph = CLFaph#(toopho, time)

'8**********************          *****************
 OPEN "a:CLFapunh.dat" FOR INPUT AS #8
 'sensible heat clf for appliances-hooded table 48

 'DIM CLFapunh#(toopho,time)
 'total operational hours 1=2hrs, 2=4hrs,3=6hrs,4=8hrs,5=10hrs,6=12hrs,7=14hrs
 ' 8=16hrs,9=18hrs
 'time  1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25=min,26=max
  DIM CLFapunh#(1 TO 9, 1 TO 26)
   FOR j = 1 TO 9
    FOR k = 1 TO 26
     INPUT #8, CLFapunh#(j, k)
    NEXT
   NEXT
   CLOSE #8
' INPUT "toopho 1,2,3,4,5,6,7,8,9"; toopho
' INPUT "time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time
 PRINT "CLFapunh"; CLFapunh#(toopho, time)
 CLFapunh = CLFapunh#(toopho, time)

' program to divide the year into 12 month
 ' DIM mnt(370), mxt(370), t(370), hum(370), day(370), month, rfcltdcorr(370), LMrf(12),
nwlcltdcorr(370), ewlcltdcorr(370), swlcltdcorr(370), wwlcltdcorr(370), CLTDgconcorr(370)

   ' ROOFS CLTDcorr
'9********************************************************************
 OPEN "a:ROOFCLTD.DAT" FOR INPUT AS #9

   ' ROOFS CLTD
   'cltd matrix for calculating cooling load from FLAT ROOFS .
```

```
'ROOFTYPE without suspended ceiling 1,2,3,4,5,6,7,8,9,10,11,12,13

'ROOFTYPE without suspended ceiling 14,15,16,17,18,19,20,21,22,23,24,25,26
'time of day  1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25=MIN,26=MAX
'DIM rfcltd#(rooftype, time)
 DIM rfcltd#(1 TO 26, 1 TO 26)

   FOR j = 1 TO 26
     FOR k = 1 TO 26
     INPUT #9, rfcltd#(j, k)
      NEXT
    NEXT
     CLOSE #9
'  INPUT "rooftype 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; rooftype
' INPUT "input time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time

PRINT "rfcltd"; rfcltd#(rooftype, time)
rfcltd = rfcltd#(rooftype, time)
'***********************
 ' PRINT "CLFGINSHn"; CLFGINSH#(1, time)

PRINT "time"; time
PRINT "toopho"; toopho
PRINT "abvalues"; abvalues
PRINT "rooftype"; rooftype
PRINT "latitude"; latitude
PRINT "tR"; tR
'***********************

'9**********************************************************************
'12*******************          *****************
 OPEN "a:CLTDGCON.DAT" FOR INPUT AS #12
 '(CLTDgcon)  cooling load temperature differences for conduction through glass
 'time of day 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25=min,26=max
 'DIM CLTDgcon#(time)
 DIM CLTDgcon#(1 TO 26)

  FOR j = 1 TO 26
   INPUT #12, CLTDgcon#(j)
  NEXT
  CLOSE #12
' INPUT "input time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time

  PRINT "CLTDgcon"; CLTDgcon#(time)
  CLTDgcon = CLTDgcon#(time)
   ' FOR i = 1 TO 365

   '  PRINT "CLTDgconcorr"; CLTDgconcorr(i)
   ' NEXT
'12********************          *******************

'11***************          *****************
 OPEN "a:ALLWALLS.DAT" FOR INPUT AS #11
       ' ALL WALLS CLTD
 'cltd matrix for calculating cooling load from sunlit walls .
 'AWALLS orientation 1=N, 2=NE, 3=E, 4=SE, 5=S, 6=SW, 7=W, 8=NW
 'BWALLS orientation 9=N, 10=NE, 11=E, 12=SE, 13=S, 14=SW, 15=W, 16=NW
 'CWALLS orientation 17=N , 18=NE, 19=E, 20=SE, 21=S, 22=SW, 23=W, 24=NW
 'DWALLS orientation 25=N , 26=NE, 27=E, 28=SE, 29=S, 30=SW, 31=W, 32=NW
```

```
'EWALLS orientation 33=N , 34=NE, 35=E, 36=SE, 37=S, 38=SW, 39=W, 40=NW
'FWALLS orientation 41=N , 42=NE, 43=E, 44=SE, 45=S, 46=SW, 47=W, 48=NW
'GWALLS orientation 49=N , 50=NE, 51=E, 52=SE, 53=S, 54=SW, 55=W, 56=NW

    'time of day 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25=MIN,26=MAX
    'DIM cltd#(orientation, time)
    DIM cltd#(1 TO 56, 1 TO 26)

     FOR j = 1 TO 56
       FOR k = 1 TO 26
        INPUT #11, cltd#(j, k)
       NEXT
      NEXT
      CLOSE #11

' INPUT "input time 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26"; time

    PRINT "nwlcltd"; cltd#(1, time)
      PRINT "ewlcltd"; cltd#(3, time)
        PRINT "swlcltd"; cltd#(5, time)
          PRINT "wwlcltd"; cltd#(7, time)
    nwlcltd = cltd#(1, time)
      ewlcltd = cltd#(3, time)
        swlcltd = cltd#(5, time)
          wwlcltd = cltd#(7, time)


     Kw = 1 'if dark colored or light in an industrial area
    '  Kw=.83 'if permanently medium colored (rural area)
    '  Kw = .65'if permanently light colored (rural area)
      ' tR = 24
      ' Tout = 30

'BuildingDimensions
        rfl = 65 'm
        rfw = 65 'm
        rfarea = rfl * rfw
        rfarea = 2275  'mEXP2

        ewll = 65  'm
        ewlw = 20  'm
        grsarewl = ewll * ewlw
        egl = 5  'm
        egw = 4   'm
        glarewl = egl * egw

        swll = 65  'm
        swlw = 20   'm
        grsarswl = swll * swlw
        sgll = 5 ' m
        sglw = 4   'm
        glarswl = sgll * sglw

        wwll = 65  ' m
        wwlw = 20  'm
        grsarwwl = wwll * wwlw
        wgll = 5  'm
        wgwl = 4   'm
        glarwwl = wgll * wgwl
```

```
        nwll = 65  'm
        nwlw = 20  'm
        grsarnwl = nwll * nwlw
        ngl = 5   'm
        ngw = 4   'm
        glarnwl = ngl * ngw


'BuildingDimensions


    '10************************************************************
          ' OPEN "c:\firas\SHEFF86.DAT" FOR INPUT AS #10
          FOR i = 1 TO 365
          INPUT #10, mnt(i), mxt(i), hum(i), t(i)
          NEXT
          CLOSE #10
    '10************************************************************


  k = 1
  FOR month = 1 TO 12


 IF latitude = 40 THEN GOTO FORT
 IF latitude = 48 THEN GOTO FORTYEIGHT
 IF latitude = 56 THEN GOTO FIFTYSIX


FORT:
IF month = 1 THEN tdays = 31: LMnw = -2.7: LMew = -5: LMsw = 6.1: LMww = -5: LMrf = -10.5:
      SHGFnw = 63: SHGFew = 486: SHGFsw = 801: SHGFww = 486
IF month = 2 THEN tdays = 28: LMnw = -2.7: LMew = -3.3: LMsw = 6.6: LMww = -3.3: LMrf = -
      7.7: SHGFnw = 76: SHGFew = 587: SHGFsw = 760: SHGFww = 587
IF month = 3 THEN tdays = 31: LMnw = -2.2: LMew = -1.6: LMsw = 5.5: LMww = -1.6: LMrf = -
      4.4: SHGFnw = 91: SHGFew = 688: SHGFsw = 650: SHGFww = 688
IF month = 4 THEN tdays = 30: LMnw = -1.1: LMew = 0: LMsw = 2.2: LMww = 0: LMrf = 1.6:
      SHGFnw = 107: SHGFew = 707: SHGFsw = 486: SHGFww = 707
IF month = 5 THEN tdays = 31: LMnw = 0: LMew = 0: LMsw = .5: LMww = 0: LMrf = .5: SHGFnw
      = 117: SHGFew = 694: SHGFsw = 357: SHGFww = 694
IF month = 6 THEN tdays = 30: LMnw = .5: LMew = .5: LMsw = -.5: LMww = .5: LMrf = 1.1:
      SHGFnw = 151: SHGFew = 681: SHGFsw = 300: SHGFww = 681
IF month = 7 THEN tdays = 31: LMnw = 0: LMew = 0: LMsw = .5: LMww = 0: LMrf = .5: SHGFnw
      = 120: SHGFew = 681: SHGFsw = 344: SHGFww = 681
IF month = 8 THEN tdays = 31: LMnw = -1.1: LMew = 0: LMsw = 2.2: LMww = 0: LMrf = 1.6:
      SHGFnw = 110: SHGFew = 681: SHGFsw = 470: SHGFww = 681
IF month = 9 THEN tdays = 30: LMnw = -2.2: LMew = -1.6: LMsw = 5.5: LMww = -1.6: LMrf = -
      4.4: SHGFnw = 95: SHGFew = 640: SHGFsw = 631: SHGFww = 640
IF month = 10 THEN tdays = 31: LMnw = -2.7: LMew = -3.3: LMsw = 6.6: LMww = -3.3: LMrf = -
      7.7: SHGFnw = 79: SHGFew = 568: SHGFsw = 738: SHGFww = 568
IF month = 11 THEN tdays = 30: LMnw = -2.7: LMew = -5: LMsw = 6.1: LMww = -5: LMrf = -10.5:
      SHGFnw = 63: SHGFew = 476: SHGFsw = 789: SHGFww = 476
IF month = 12 THEN tdays = 31: LMnw = -3.3: LMew = -5.5: LMsw = 5.5: LMww = -5.5: LMrf = -
      11.6: SHGFnw = 57: SHGFew = 476: SHGFsw = 798: SHGFww = 476

 GOTO MAIN
```

```
FORTYEIGHT:
IF month = 1 THEN tdays = 31: LMnw = -3.3: LMew = -6.1: LMsw = 4.4: LMww = -6.1: LMrf = -
        13.3: SHGFnw = 47: SHGFew = 372: SHGFsw = 773: SHGFww = 372
IF month = 2 THEN tdays = 28: LMnw = -3.3: LMew = -5.5: LMsw = 5: LMww = -5.5: LMrf = - 12.2:
SHGFnw = 63: SHGFew = 530: SHGFsw = 789: SHGFww = 530
IF month = 3 THEN tdays = 31: LMnw = -2.2: LMew = -2.2: LMsw = 6.1: LMww = -2.2: LMrf = -
        6.1: SHGFnw = 82: SHGFew = 644: SHGFsw = 719: SHGFww = 644
IF month = 4 THEN tdays = 30: LMnw = -1.6: LMew = -.5: LMsw = 3.8: LMww = -.5: LMrf = -2.7:
        SHGFnw = 98: SHGFew = 691: SHGFsw = 587: SHGFww = 691
IF month = 5 THEN tdays = 31: LMnw = 0: LMew = .5: LMsw = 2.2: LMww = .5: LMrf = 0:
        SHGFnw = 110: SHGFew = 290: SHGFsw = 473: SHGFww = 290
IF month = 6 THEN tdays = 30: LMnw = .5: LMew = 1.1: LMsw = 1.6: LMww = .5: LMrf = 1.1:
        SHGFnw = 145: SHGFew = 678: SHGFsw = 423: SHGFww = 678
IF month = 7 THEN tdays = 31: LMnw = 0: LMew = .5: LMsw = 2.2: LMww = .5: LMrf = 0:
        SHGFnw = 117: SHGFew = 675: SHGFsw = 461: SHGFww = 675
IF month = 8 THEN tdays = 31: LMnw = -1.6: LMew = -.5: LMsw = 3.8: LMww = -.5: LMrf = -2.7:
        SHGFnw = 104: SHGFew = 666: SHGFsw = 568: SHGFww = 666
IF month = 9 THEN tdays = 30: LMnw = -2.2: LMew = -2.2: LMsw = 6.1: LMww = -2.2: LMrf = -
        6.1: SHGFnw = 85: SHGFew = 290: SHGFsw = 694: SHGFww = 290
IF month = 10 THEN tdays = 31: LMnw = -2.7: LMew = -4.4: LMsw = 6.1: LMww = -4.4: LMrf = -
        10: SHGFnw = 66: SHGFew = 508: SHGFsw = 764: SHGFww = 508
IF month = 11 THEN tdays = 30: LMnw = -3.3: LMew = -6.1: LMsw = 4.4: LMww = -6.1: LMrf = -
        13.3: SHGFnw = 47: SHGFew = 363: SHGFsw = 757: SHGFww = 363
IF month = 12 THEN tdays = 31: LMnw = -3.3: LMew = -7.2: LMsw = 3.3: LMww = -7.2: LMrf = -
        13.8: SHGFnw = 41: SHGFew = 287: SHGFsw = 735: SHGFww = 287

    GOTO MAIN

FIFTYSIX:
IF month = 1 THEN tdays = 31: LMnw = -3.3: LMew = -7.7: LMsw = 1.1: LMww = -7.7: LMrf = -
        15: SHGFnw = 32: SHGFew = 233: SHGFsw = 647: SHGFww = 233
IF month = 2 THEN tdays = 28: LMnw = -3.3: LMew = -5.5: LMsw = 5: LMww = -5.5: LMrf = - 12.2:
SHGFnw = 50: SHGFew = 439: SHGFsw = 770: SHGFww = 439
IF month = 3 THEN tdays = 31: LMnw = -2.7: LMew = -2.7: LMsw = 6.6: LMww = -2.7: LMrf = -
        8.3: SHGFnw = 69: SHGFew = 548: SHGFsw = 760: SHGFww = 548
IF month = 4 THEN tdays = 30: LMnw = -1.6: LMew = -.5: LMsw = 5: LMww = -.5: LMrf = -4.4:
        SHGFnw = 88: SHGFew = 666: SHGFsw = 663: SHGFww = 666
IF month = 5 THEN tdays = 31: LMnw = 0: LMew = 1.1: LMsw = 3.8: LMww = 1.1: LMrf = -1.1:
        SHGFnw = 114: SHGFew = 678: SHGFsw = 571: SHGFww = 678
IF month = 6 THEN tdays = 30: LMnw = 1.1: LMew = 1.6: LMsw = 3.3: LMww = 1.6: LMrf = .5:
        SHGFnw = 167: SHGFew = 672: SHGFsw = 530: SHGFww = 672
IF month = 7 THEN tdays = 31: LMnw = 0: LMew = 1.1: LMsw = 3.8: LMww = 1.1: LMrf = -1.1:
        SHGFnw = 117: SHGFew = 666: SHGFsw = 558: SHGFww = 666
IF month = 8 THEN tdays = 31: LMnw = -1.6: LMew = -.5: LMsw = 5: LMww = -.5: LMrf = -4.4:
        SHGFnw = 95: SHGFew = 640: SHGFsw = 640: SHGFww = 640
IF month = 9 THEN tdays = 30: LMnw = -2.7: LMew = -2.7: LMsw = 6.6: LMww = -2.7: LMrf = -
        8.3: SHGFnw = 73: SHGFew = 540: SHGFsw = 729: SHGFww = 540
IF month = 10 THEN tdays = 31: LMnw = -3.3: LMew = -5.5: LMsw = 5: LMww = -5.5: LMrf = -
        12.2: SHGFnw = 50: SHGFew = 416: SHGFsw = 738: SHGFww = 416
IF month = 11 THEN tdays = 30: LMnw = -3.3: LMew = -7.7: LMsw = 1.1: LMww = -7.7: LMrf = -
        15!: SHGFnw = 32: SHGFew = 227: SHGFsw = 631: SHGFww = 227
IF month = 12 THEN tdays = 31: LMnw = -3.8: LMew = -8.8: LMsw = -1.6: LMww = -8.8: LMrf = -
        15.5: SHGFnw = 22: SHGFew = 148: SHGFsw = 540: SHGFww = 148

    GOTO MAIN

MAIN:

  FOR days = 1 TO tdays
```

```
'*****************************************************************************
            Krf = 1   ' if dark colored or light in an industerial area
        '   Krf = .5  ' if permanently light-colored (rural area)

            F = 1      ' no attic OR ducts
        '   f = .75    ' positve ventilation
                 'f is a facter for attic fan and ducts above
                 'ceiling applied after all other adjustments

     ' tR = 24
     Todave(k) = ((mxt(k) + mnt(k)) / 2)
  rfcltdcorr(k) = ((rfcltd + LMrf) * Krf + (25.5 - tR) + (Todave(k) - 29.4)) * F
  nwlcltdcorr(k) = (cltd#(1, time) + LMnw) * Kw + (25.5 - tR) + (Todave(k) - 29.4)
  ewlcltdcorr(k) = (cltd#(3, time) + LMew) * Kw + (25.5 - tR) + (Todave(k) - 29.4)
  swlcltdcorr(k) = (cltd#(5, time) + LMsw) * Kw + (25.5 - tR) + (Todave(k) - 29.4)
  wwlcltdcorr(k) = (cltd#(7, time) + LMww) * Kw + (25.5 - tR) + (Todave(k) - 29.4)
  CLTDgconcorr(k) = CLTDgcon#(time) + (25.5 - tR) - (29.4 - Todave(k))
'****************************************************************************

  ' SOLAR LOAD
'**********************
  ' EAST

  a = glarewl
  SC = .55  'table 29 page 27.33 for 6 mm glass
 ' SHGF = 685  'at lat 52N may  page 26.39 table 34
 ' clf = .8  '  page 26.41 table 36 to 39
  qse = a * SC * SHGFew * CLFGINSHe
 ' PRINT " qse "; qse

'**************************



  ' SOUTH
  a = glarswl
  SC = .55  'table 29 page 27.33 for 6 mm glass.35
 ' SHGF = 789 ' feb. lat 52N page 26.40 table 34
 ' clf = .83  'at 12.00 page 26.43 tble 39a
  qss = a * SC * SHGFsw * CLFGINSHs
 ' PRINT " qss "; qss

  ' WEST
  a = glarwwl
  SC = .55   ' feb. lat 52N page 26.40 table 34
 ' SHGF = 685  ' may. lat 52N page 26.40 table 34'
 ' clf = .82   ' at 16.00 page 26.43 table39 glass with interior shading
  qsw = a * SC * SHGFww * CLFGINSHw
 'PRINT " qsw "; qsw

  ' NORTH
  a = glarnwl
  SC = .55   ' feb. lat 52N page 26.40 table 34.29
 ' SHGF = 142  ' june lat 52N page 26.40 table 34'
 ' clf = .89   ' north at 14.00 pm glass with interior shading
         'page 26.43 table
  qsn = a * SC * SHGFnw * CLFGINSHn
 ' PRINT " qsn "; qsn
```

```
'*************************************************************************

    ' LPRINT days, month, LMrf, mxt(k), rfcltdcorr(k), SHGFnw, SHGFew, SHGFsw, SHGFww
    ' LPRINT month, qsn, qss, qsw, qse
    'LPRINT nwlcltdcorr(k), ewlcltdcorr(k), swlcltdcorr(k), wwlcltdcorr(k), CLTDgconcorr(k)
     k = k + 1
       NEXT
       NEXT
'**********************************
    ' PRINT "nwlcltdcorr"; nwlcltdcorr
    ' PRINT "ewlcltdcorr"; ewlcltdcorr
    ' PRINT "swlcltdcorr"; swlcltdcorr
    ' PRINT "wwlcltdcorr"; wwlcltdcorr
 '11********************        ********************

'SUB*********************************************************************
    ' OPEN "c:\firas\SHEFF86.DAT" FOR INPUT AS #1
    ' OPEN "a:\sicltdjr.DAT" FOR OUTPUT AS #2
     ' INPUT "input latitude 30,40,50"; latitude
     ' INPUT "input month 1,2,3,4,5,6,7,8,9,10,11,12"; month
    FOR i = 1 TO 365
   ' INPUT #1, mnt(i), mxt(i), hum(i), t(i)
    patm = 1013.25
    pws(i) = 6.108 * EXP(17.245 * t(i) / (237.3 + t(i)))'mbar
    pw(i) = hum(i) * pws(i) / 100
    w(i) = .622 * pw(i) / (patm - pw(i))



    'procedure to calculate space design cooling load in SI units


    ' for roof  ' R(si)=R(imperial)*0.1761102
              ' R=(mEXP2 * c)/w
              ' U=w/(mEXP2 * c)
              'r=thermal resistance
              'u=thermal conductance


    r1rf = .99   ' (mEXP2 * c)/w
    r2rf = .97   ' (mEXP2 * c)/w
    rtrf = r1rf + r2rf

    rfu = 1 / rtrf   ' w/(mEXP2 * c)
   ' rfarea = 2275  'mEXP2
   '  CLTDcorr=[(cltd+LM)*K+(25.5-tr)+(to-29.4)]*f  page 26.35
                                   'table 29

    rfq(i) = rfu * rfarea * rfcltdcorr(i)
   ' PRINT "rfq"; rfq

    ' for walls
    'east wall
    ewlr1 = .05  ' (mEXP2 * c)/w
    ewlr2 = .07
    ewlr3 = .08
    ewlr4 = .136
    ewlrt = ewlr1 + ewlr2 + ewlr3 + ewlr4
```

```
 ewlu = 1 / ewlrt    ' (mEXP2 * c)/w
' ewll = 35  'm  :' ewlw = 20  'm
' grsarewl = ewll * ewlw

 'for glass

 'east glass

 egr1 = .105     ' (mEXP2 * c)/w
 egr2 = .123
 egrt = egr1 + egr2
 eglu = 1 / egrt    ' (mEXP2 * c)/w
' egl = 5  'm  :' egw = 4   'm
' glarewl = egl * egw
 netarewl = grsarewl - glarewl
 eglq(i) = eglu * glarewl * CLTDgconcorr(i)
 ' PRINT " eglq"; eglq

 ewlq(i) = ewlu * netarewl * ewlcltdcorr(i)
 'PRINT " ewlq"; ewlq

 'south wall

 swlr1 = .05       '(mEXP2 * k)/w
 swlr2 = .07
 swlr3 = .08
 swlr4 = .03
 swlrt = swlr1 + swlr2 + swlr3 + swlr4
 swlu = 1 / swlrt      '  w/(mEXP2 *k)
' swll = 65  'm  :' swlw = 20   'm
' grsarswl = swll * swlw

 'for glass
 'south glass

 sglr1 = .105        '(mEXP2 * k)/w
 sglr2 = .123        '(mEXP2 * k)/w
 sglrt = sglr1 + sglr2
 sglu = 1 / sglrt      '  w/(mEXP2 *k)
' sgll = 1.5 ' m  :' sglw = 2   'm
' glarswl = sgll * sglw
 netarswl = grsarswl - glarswl

 sglq(i) = sglu * glarswl * CLTDgconcorr(i)
'PRINT "sglq"; sglq
'PRINT "glarswl"; glarswl
'PRINT "CLTDgconcorr "; CLTDgconcorr
' PRINT "sglu"; sglu
 swlq(i) = swlu * netarswl * swlcltdcorr(i)
 'PRINT "swlq"; swlq

 'west wall

 wwlr1 = .05      '(mEXP2 * k)/w
 wwlr2 = .07
 wwlr3 = .08
 wwlr4 = .03
 wwlrt = wwlr1 + wwlr2 + wwlr3 + wwlr4
 wwlu = 1 / wwlrt
```

```
' wwll = 50  ' m:' wwlw = 30  'm
' grsarwwl = wwll * wwlw

 'for glass

 'west glass
 wgr1 = .6     '(mEXP2 * k)/w
 wgr2 = .7
 wgrt = egr1 + egr2
 wglu = 1 / wgrt
' wgll = 1.5  'm  :' wgwl = 2   'm
' glarwwl = wgll * wgwl
 netarwwl = grsarwwl - glarwwl

 wglq(i) = wglu * glarwwl * CLTDgconcorr(i)
' PRINT "wglq"; wglq

 wwlq(i) = wwlu * netarwwl * wwlcltdcorr(i)
' PRINT " wwlq"; wwlq

 'north wall

 nwlr1 = .05    '(mEXP2 * k)/w
 nwlr2 = .07
 nwlr3 = .08
 nwlr4 = .03
 nwlrt = nwlr1 + nwlr2 + nwlr3 + nwlr4
 nwlu = 1 / nwlrt   'w/(mEXP2 *k)
' nwll = 50  'm  :' nwlw = 30  'm
' grsarnwl = nwll * nwlw

 'for glass

 'north glass
 ngr1 = .105    '(mEXP2 * k)/w
 ngr2 = .123
 ngrt = ngr1 + ngr2
 nglu = 1 / ngrt    'w/(mEXP2 *k)
' ngl = 1.5   'm  :' ngw = 2   'm
' glarnwl = ngl * ngw
 netarnwl = grsarnwl - glarnwl

 nglq(i) = nglu * glarnwl * CLTDgconcorr(i)
' PRINT " nglq"; nglq

 nwlq(i) = nwlu * netarnwl * nwlcltdcorr(i)
' PRINT " nwlq"; nwlq

  ' solar has moved

 'PARTITIONS,CEILING,FLOORS

 ' q = U * A * TD


 ' INTERNAL LIGHTS
' clf = .93 'at 14.00  14 hrs of operation,12 in conc. 150 mm.
        'floor,medium air circulation & any type of furniture.
        'page 26.45 table 46
```

```
        'a=.75 ,b=c page 26.44 table 41,42

 watt = 90000      'fluorescent
 usefactor = .95   'for commercial =1
                'page 26.46
 Fsa = 1.2         'special allowance, fluorescent
 Qlight = watt * Fsa * usefactor * CLFLIT14
 ' PRINT "Qlight"; Qlight

 ' PEOPLE
 nop = 1000
 sens.h.g. = 75  'w page 26.7 table 3 moderately active office work
' clf = .89 'total hours in space 10, page 26.44 table 40
        ' 10 hrs after each entry into space
 qs = nop * sens.h.g. * CLFPEOPL

 ' PRINT "qs"; qs
  lat.h.g. = 55  'w

  ql = nop * lat.h.g.      ' 3410   btu/hr=1kw
 ' PRINT "ql"; ql          ' 3.410  btu/hr=1w

 '  APPLIANCES
' clf = .84    '10 hrs operation & after 10 hrs appliances are on.
          'unhooded.page 26.46 table 48
 Fr = .32 'fraction of the input energy of the hooded appliance
        'released by radiation page 26.9
 Fu = .5  'usage factor page 26.11 or page 26.9 table 6
 wattage = 100000 'watt page 26.11 table 9
         'water cooler,shredder,m.wave,coppier,printer,w.processer.

 'sensible portion = .66 'page 25.20 ASHRAE  FUND. 1977
 'latent portion = .34
 h.g. = wattage
  qsa = h.g. * Fu * Fr * CLFapunh * .66
 ' PRINT "qsa"; qsa


  qla = h.g. * .34   'each served meal transfers 15w
                'in which 75% sens., 25%lat.

 ' PRINT "qla"; qla


  'POWER        'page 26.8
  power = 10000
 m.efficiency = 81    'page 26.9 table 5
 Flm = 1          'MOTOR load factor  page 26.9 table 5
 Fum = 1    'MOTOR use factor for conventional application page 26.8

 ' both the motor and driven equipment are assumed to be within
 'the condition space.

 h.g.p. = (power / (m.efficiency/100 )) * Flm * Fum ' page 26.8


' clf = .95    '10 hrs operation & after 10 hrs appliances are on.
          'unhooded.page 26.46 table 49
```

```
        qp = h.g.p. * CLFapunh
       ' PRINT "qp"; qp


        'VENTILATION & INFILTRATION AIR


   '2**********************          *****************


    n = time

    pie = 22 / 7

   Tamb(i) = (mxt(i) - mnt(i)) / 2 + mnt(i) + (SIN(((15 + n) / 24) * 2 * pie) * -1 * (mxt(i) - mnt(i)) / 2)

 IF time = 26 THEN Tout(i) = mxt(i)
 IF time = 25 THEN Tout(i) = mnt(i)
 IF (time >= 1) AND (time <= 24) THEN Tout(i) = Tamb(i)


   'LPRINT Tout
   '2*********************       ********************



         designt = tR
        ' designt = 24   'degree C
         dt = Tout(i) - designt   'dt=Tout-Tin
         Q = 7 * nop    'institutional,classroom page26.12
                    '7 L/S/person
         nop = 1000


         qsv(i) = 1.23 * Q * dt
        '  PRINT "qsv"; qsv


         ' designw = .009312     'at 24 degree C, 50%rh, page25.23
                         'w = kg water /kg dry air
         dw = w(i) - designw    'dw= wout-win


          qlv(i) = 3010 * Q * dw
        ' PRINT "qlv"; qlv

         '  q = 1.2 * Q * dh
         'dh=(out -in )  page 26.12
         'the constants 1.2,1.23 and 3010 are used in air conditioning
         'calculations at sea level(101.325 kpa) and for normal
         'temperatures and moisture ratios.For other conditions more
         ' precise values should be used .For an altitude of 1500m(84.556Kpa)

         'the appropriate'values are 1.00,1.03,and 2500.

 'infiltration***********************
           ' INFILTRATION AIR  / Crack Method

              'Air Conditioning Principles and Systems
```

```
        'An Energy Approach 'Edward G Pita
        'table 3.3 page 58 recommended maximum allowed designed
         'infiltration rates through exterior windows and doors

     ' windows Infiltration = .75   'cfm/ft crack
     '  1 cfm = 1.7                 ' m^ 3/hr
     ' therefor win inf=1.275       ' m^ 3/hr/ft
     ' win inf = 4.25               ' m^ 3/hr/m crack


      wininf = 1.180555   'L/S/M


     designt = tR
    ' designt = 24   'degree C

    dt = Tout(i) - designt

     'dt = mxt(i) - designt   'dt=Tout-Tin


     'from page 63 building infiltration loss
     'we have to find the infiltration  L/S on each side of the
     'building ,then select the greatest and compare it with one_half
     'the sum of the infiltration on all sides of the building then use
     'the greater value

     'in this building east side window has greatest circumference value
     'but less than one_half circumference value on all sides

     circumference = 2 * (egl + egw + sgll + sglw + wgll + wgwl + ngl + ngw)
     Qinf = wininf * circumference
      qsinf(i) = 1.23 * Qinf * dt
    '  PRINT "qsinf"; qsinf


      ' designw = .009312     'at 24 degree C, 50%rh, page25.23
                           'w = kg water /kg dry air
     dw(i) = w(i) - designw    'dw= wout-win


      qlinf(i) = 3010 * Qinf * dw
     ' PRINT "qlinf"; qlinf
'infiltration**************************

   ' TOTALQ =rfq(i)+ eglq(i) + ewlq(i) + sglq(i) + swlq(i) + wglq(i) +
         'wwlq(i) + nglq(i) + nwlq(i) + qse + qss + qsw + qsn+ Qlight +
       'qs ql + qsa + qla + qp + qsv(i) + qlv(i) + qsinf(i) + qlinf(i)

  QTOTAL1 = rfq(i) + eglq(i) + ewlq(i) + sglq(i) + swlq(i) + wglq(i) + wwlq(i)
  QTOTAL2 = nglq(i) + nwlq(i) + qse + qss + qsw + qsn + Qlight
  QTOTAL3 = qs + ql + qsa + qla + qp + qsv(i) + qlv(i) + qsinf(i) + qlinf(i)

   TOTALQ(i) = QTOTAL1 + QTOTAL2 + QTOTAL3  'WATTS


BAK:
     pc$ = "##.######"
    ' LPRINT i, TOTALQ(i), Tout(i), USING pc$; w(i)
```

```
        ' WRITE #2, i, TOTALQ(i), Tout(i), w(i), qsv(i), qlv(i)

        ' WRITE #2, i, TOTALQ(i)

        '  WRITE #2, i, rfq(i)

        ' WRITE #2, i, TOTALQ(i), Tout(i), w(i), qsinf(i), qlinf(i)

        ' WRITE #2, TOTALQ(i), w(i)
        ' WRITE #2, qsv(i), qlv(i)
         WRITE #2, w(i)

  ' TOTALQ = rfq(i)+ eglq(i) + ewlq(i) + sglq(i) + swlq(i) + wglq(i) +
         ' wwlq(i) + nglq(i) + nwlq(i) + qse + qss + qsw + qsn+ Qlight +
         ' qs +  ql+ qsa + qla + qp + qsv(i) + qlv(i)+ qsinf(i) + qlinf(i)

'LPRINT i, rfq(i), eglq(i), ewlq(i), sglq(i)
'LPRINT i, swlq(i), wglq(i)
'LPRINT i, wwlq(i), nglq(i), nwlq(i)
'LPRINT i, qse, qss, qsw, qsn, Qlight
'LPRINT i, qs, ql, qsa, qla
'LPRINT i, qp, qsv(i), qlv(i)
'LPRINT i, qsinf(i), qlinf(i)
'LPRINT dw(i), qlv(i), w(i)
'LPRINT Tout(i), designt, designw, w(i)

         'IF (i / 60) = INT(i / 60) THEN GOTO SKIP

         NEXT i
         CLOSE #1
         CLOSE #2
         END
SKIP:
        FOR L = 1 TO 6
        LPRINT
        NEXT L
        GOTO BAK
```

Appendix B

Input Data

LEEDS 1986

****

2.5	4.7	90	3.4
0.5	4.3	98	1
0.6	3.6	75	1.7
-3.6	2.3	84	-2.7
-0.6	3.6	96	-0.3
0.4	2	82	1.3
-3.3	2.3	82	-2.3
0.3	1.3	93	0.7
0.4	4	95	0.6
3.6	10.7	88	7
4.3	7	66	5.9
2.9	8.10	71	5.4
7.7	11.1	76	9.7
3.4	6.3	92	4.5
5.5	6.8	79	5.9
0.4	4.5	61	0.9
-2.6	3.9	92	-1.3
3.6	9.8	88	10.1
7.6	10.6	80	10.5
4.3	9.10	75	6
5.3	7.2	78	6.2
2.3	9.39	67	3
2.3	6	75	3.5
0.5	4	70	0.6
-1.6	4.3	71	-1.4
-6	3.3	75	-5.3
0.5	4.5	91	2
-0.5	4.8	85	1
0.3	2.1	97	0.4
1	4.5	91	3.5
2.5	3.3	88	2.8
1.5	3.5	94	2.3
2	2.4	89	2.5
1	2.6	93	1.1
0.8	2.7	94	0.9
-1	2.6	91	-0.8
-2.1	1.4	94	-0.8
-1.6	0.9	90	-0.6
-1	1.2	91	-0.8
-0.5	0.9	94	-0.1
-4	0.3	100	-3.6
-8.5	1.3	91	-8
-1.3	0	89	-0.9
-2	3.1	96	-1.6
-1.7	-0.1	92	-0.4
-0.4	0.8	78	-0.3
-0.8	1.2	88	0.1
-0.1	2.5	79	0.3

-0.6	2.3	69	0.8
-0.6	1.9	88	-0.4
-3.3	0.9	96	-2.5
-6.7	-0.4	89	-6.5
-4.5	2.6	85	-3.9
-3.8	0.6	81	-3
-3.1	4	88	-1.5
-1.7	2	88	-0.6
-3.1	0.2	83	-2.8
-3.2	2	75	-2.6
-0.8	2.8	87	-0.6
-1.1	3.1	74	-0.4
-3	3.3	82	-2.6
-6.6	4.3	88	-6.5
2.2	10.5	88	4.9
7.3	9.5	79	8.6
3.2	8.2	77	3.5
2.9	9.5	92	3.5
-0.5	11.1	88	0.3
1.5	6.5	82	2.8
2.2	9.39	97	3
0	7.3	98	0.3
2.2	6.1	98	2.2
0.7	3.7	91	1.2
2	10.2	91	2.3
7.9	10.6	88	8.1
4.7	8.5	87	4.7
3.1	11	90	3.5
2.2	9.2	84	2.3
3.6	12.4	89	4.2
4	9.6	81	6
4.2	10.9	77	5.1
6.8	13.7	76	8
3.7	7.5	60	4.8
0.5	4.2	97	0.6
2.4	9.5	72	3
3.7	9.2	84	4
5	10.7	83	7.8
4.1	10.3	77	5.2
4.5	10.6	78	5.5
1.1	7.4	76	1.7
0.8	7.8	97	1.5
1.7	10.3	91	2
0.5	9.7	90	1.1
-1.2	9.5	95	1
1.8	7.6	91	1.8
1.2	7.3	86	1.3
1	5.1	91	1.4
-0.1	3.6	81	0.9
1.1	4.4	96	1.3
2.7	8	82	2.9
1.7	5.2	73	2.5
1	8.5	74	1.2
3.4	7.8	90	5
1.1	8.2	83	2
3	7	92	4
4.5	6.4	91	5
3.7	7.8	95	3.8
4.3	5.9	86	4.9

3.1	7	80	3.4
1.6	9.3	80	1.8
5.4	11	82	6.8
4	8.8	84	4.8
0.5	11.3	93	2.1
2.2	11.6	97	3.4
5.4	11.8	94	6.6
3	14.2	96	3.7
2	16	100	2.5
5.3	14	86	5.9
3	12	73	5.6
3.8	13.4	84	4.6
5.5	16	72	6.5
7	21.1	76	8.8
6.9	20	75	7.8
8.89	20	92	9.6
5.5	13.8	92	6.4
7.5	12.7	83	9.2
5.5	16.4	85	6.8
7	15.6	95	7.8
6.7	13.8	83	8
6.5	14	74	7.9
11.5	16.5	76	14.5
9.2	14.7	84	10
9.39	16.8	79	11.5
7.2	13.8	74	8.5
6.9	13.5	77	8.2
4.6	12	80	5.5
4.2	16.7	80	7.8
5.9	14.6	77	9.10
11.7	15.7	68	12.9
9.7	19.5	82	11.3
10.6	15.5	90	11.1
9.5	12.8	67	10.3
7.5	15.7	83	7.8
10	16.3	72	10.5
9.2	15.3	93	9.7
9.6	17.6	71	13
11.4	17	77	12.4
9.10	14.2	68	9.8
6.4	14.6	71	8.6
6	15.5	79	7.3
7.5	14	81	9.2
8.89	16.6	75	9.39
12	19.5	89	12.6
12.9	19.1	86	13.5
12.8	17.3	83	13.3
6.5	14.2	63	8
6.7	12.8	65	8.399999
7.5	14.7	79	7.5
6	17	79	8.8
8	17.4	60	9.3
12.2	20.3	78	13.5
11.5	15.1	94	12.1
7.9	16	85	8.8
5	19.5	83	9
13	20.7	75	13.2
13.2	24.5	89	14.2
12.2	22.2	69	14.4

11.5	26.2	79	13
15.2	25	85	17
10.8	17.6	73	11
9.1	18.7	93	9.39
9.1	14.8	82	11.2
8.5	18	78	8.5
9.7	15.4	90	10.4
9.2	15.9	79	9.5
9.5	20.8	95	10
13.4	22.9	74	14.1
14.3	23.8	80	15.2
13	25.9	88	13.2
13.5	26.5	75	15.7
13	24.9	79	14.7
12	21.5	95	12
14.3	24.7	79	14.5
13.9	26.6	83	15
12.7	22.4	86	13.2
14.9	19.7	79	15
13.5	18	84	14.3
11	18.8	83	13
11.2	17.8	65	12.7
13	20.9	81	13.6
9	18	79	10.3
12.9	20.4	74	13.4
9.6	19.6	83	12.5
11.7	14.7	94	12
11	21.2	90	11.9
16.4	25.8	87	17.2
18.6	26.2	89	18.7
17.5	28.6	78	18.4
13.1	17	76	13.8
10.7	19	79	12.7
11	17.5	70	11.5
13.1	20.8	85	14.9
11.5	17.8	87	12.8
9	15.9	82	10.7
10.5	15	82	10.7
8.2	20.1	82	9.89
14.1	16.8	77	14.2
11.5	19.9	88	12.5
10.3	21.1	80	12.2
15.4	19.5	84	15.7
15.5	18.4	86	16
10.9	14.3	86	11.5
12	17.7	88	12.8
8.6	20	87	9.39
12.8	18.8	72	14.5
10.9	17.3	83	11.5
11.1	19.5	91	11.3
11.1	19.2	89	11.9
12.9	18.6	80	13
13	18.1	86	13.7
13.1	19.4	82	13.4
8.5	20.7	88	9.5
10.5	18.9	86	11.4
11.5	13.4	90	11.8
11.7	17.4	91	11.8
12	18.2	90	12

14.5	20.2	91	15.8
12.3	16.2	69	12.5
9.6	16.2	87	10.2
11.3	20.2	82	12.7
8.5	15.8	96	8.60
8.7	19.1	96	8.7
8.2	19.7	95	8.5
6.5	16.8	98	6.5
11.1	12.4	87	11.7
8.3	17.6	87	9
7	17.5	87	7.9
8.89	14.5	88	9
10.4	14.7	97	13.1
9.5	13	80	9.89
8.5	17	86	8.89
8	14.5	86	8.3
10	16.5	79	10.6
5.6	16.3	95	5.8
10.7	18.9	88	11.8
12.5	17.5	70	12.5
8.5	13.6	92	10.1
7.6	16.3	91	8.3
9.89	17.5	69	11.4
10.5	16.2	74	11.7
6.5	16.5	92	7.5
8.6	16	86	9
4.1	15.9	94	4.1
7	16.2	82	7.9
3.4	15	96	3.4
5.9	14.8	84	7.1
2.3	15.3	99	2.3
5	14.9	92	5.1
2.8	12.7	91	2.8
2.6	15.1	89	2.6
2.6	14.5	76	3.3
5.1	14.5	85	5.8
2.5	16.4	94	2.8
9.8	19.3	89	11.5
11.2	16.4	75	11.4
12.1	17.4	82	12.8
12.5	17.5	85	12.5
10.3	14.8	90	10.5
4.7	16.4	96	5
4.5	15.9	97	4.5
9	17.2	95	9.39
12.8	20.2	87	14
14.5	19.2	89	14.6
10.5	21.8	97	10.5
7.7	15.2	93	7.9
11.3	16.5	84	11.8
6.3	19.3	93	6.6
7.2	17.3	87	7.6
10.8	19	96	10.9
13.7	19	83	13.7
14	17	78	15
9.10	18.7	98	9.8
12.8	16.4	83	13
11.5	14.5	91	11.5
4.3	15.6	97	5.4

1.5	14.4	60	1.8
11.9	14.2	89	12
11.9	15.5	92	12.6
5.6	15.7	94	6.5
3.1	16.2	90	3.6
3.9	15.5	99	4.8
6.5	12.7	88	8.2
5	8.8	77	5.3
5.2	9.5	92	5.9
6.2	10.7	96	6.3
8	10.5	73	8.8
3.5	10.3	70	5.9
5.4	10.6	91	6.1
7.7	12	76	9.2
7.6	11.9	62	7.6
9	16.8	84	11.9
13.9	17.4	88	14.7
6.1	11	77	6.5
8.3	12.5	71	11.5
6.7	10.2	83	7
4.5	8.3	89	4.5
2	10.5	84	3
4.3	12.6	82	7
3.5	11	90	3.8
8.5	12.8	75	9.7
6.5	10.6	71	6.9
5.7	15.3	87	8.8
4.9	9.39	87	5.6
6	12.8	78	7.5
11	13.6	89	11.8
7.5	11.8	81	12.5
3.1	10.2	86	3.7
7	13	92	10.5
6.6	11.1	86	7.7
6.8	10.8	84	7.7
7.9	12.3	64	10.8
3.8	8.3	87	4.2
3.8	7.9	85	5.8
5.8	9.39	89	7.3
3.4	8.8	74	4.9
1	6.9	93	3.2
4.6	9	79	7.5
3.7	9.8	90	4.1
5.5	14	87	8.10
12.3	15	69	12.7
5.7	8.3	79	6.6
6.2	11.1	80	7.6
8	11.8	81	9.39
6	11.6	77	6.4
2.5	5.8	94	3.1
4.5	12.3	82	8.5
5.9	12.8	82	6
9.3	14.5	70	10
8.6	14.9	78	9.3
11.5	13	77	14.1
2.6	7.1	85	3.4
2.6	10.9	84	5
7	10.6	97	7.7
5.5	7.9	73	6

1.5	6.2	90	2.5
3.2	9.1	91	5.8
0.9	7	92	1.4
5.5	7.5	91	6.3
0.3	5.2	92	0.3
0.1	9.7	79	2.9
2.2	7	72	3.2
5	9	79	6
4.5	6.2	66	6.6
0.8	6	70	2.7
3.1	6.2	74	3.7
1.5	5.7	76	2.4
1.4	4	78	2
0.6	5.5	65	2.8
1.1	6.7	81	1.4
6.2	9	92	8.6
3	6.4	80	3.5
2	7	74	4
6.4	11.5	78	7.2
9.3	11.3	70	10.3
5.6	12.2	96	6.1
6.1	9	87	7.6
4.5	7	93	4.7

Appendix C

Output Data in a Graphical Form

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FIGURE-1-SHEFFIELD 1988 TOTAL COOLING LOAD USING DIFFERENT INDOOR DESIGN TEMPERATURES

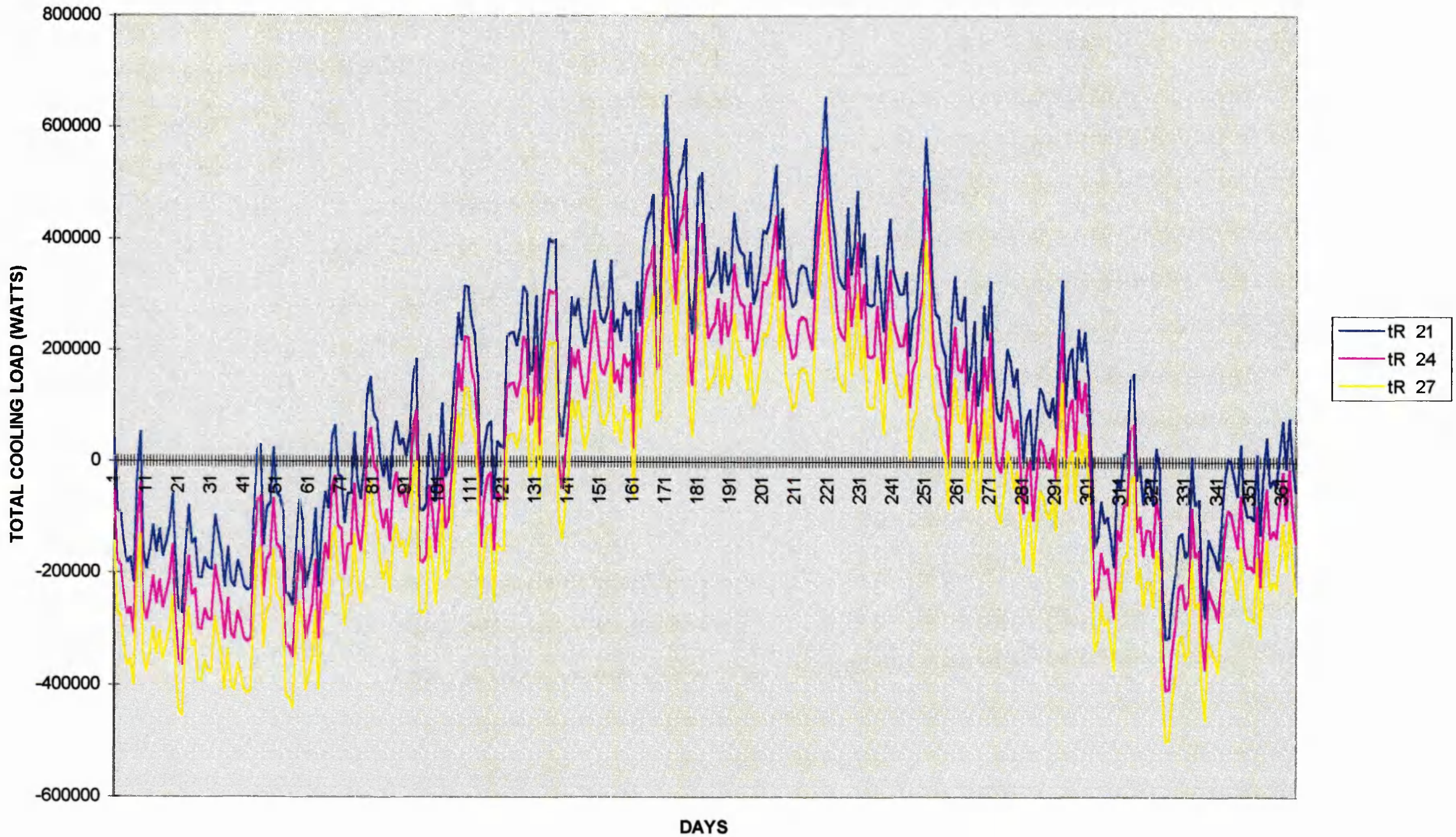


Figure -2- Cooling load for a specified building in Erie, USA 1988 at latitude 40 degrees north

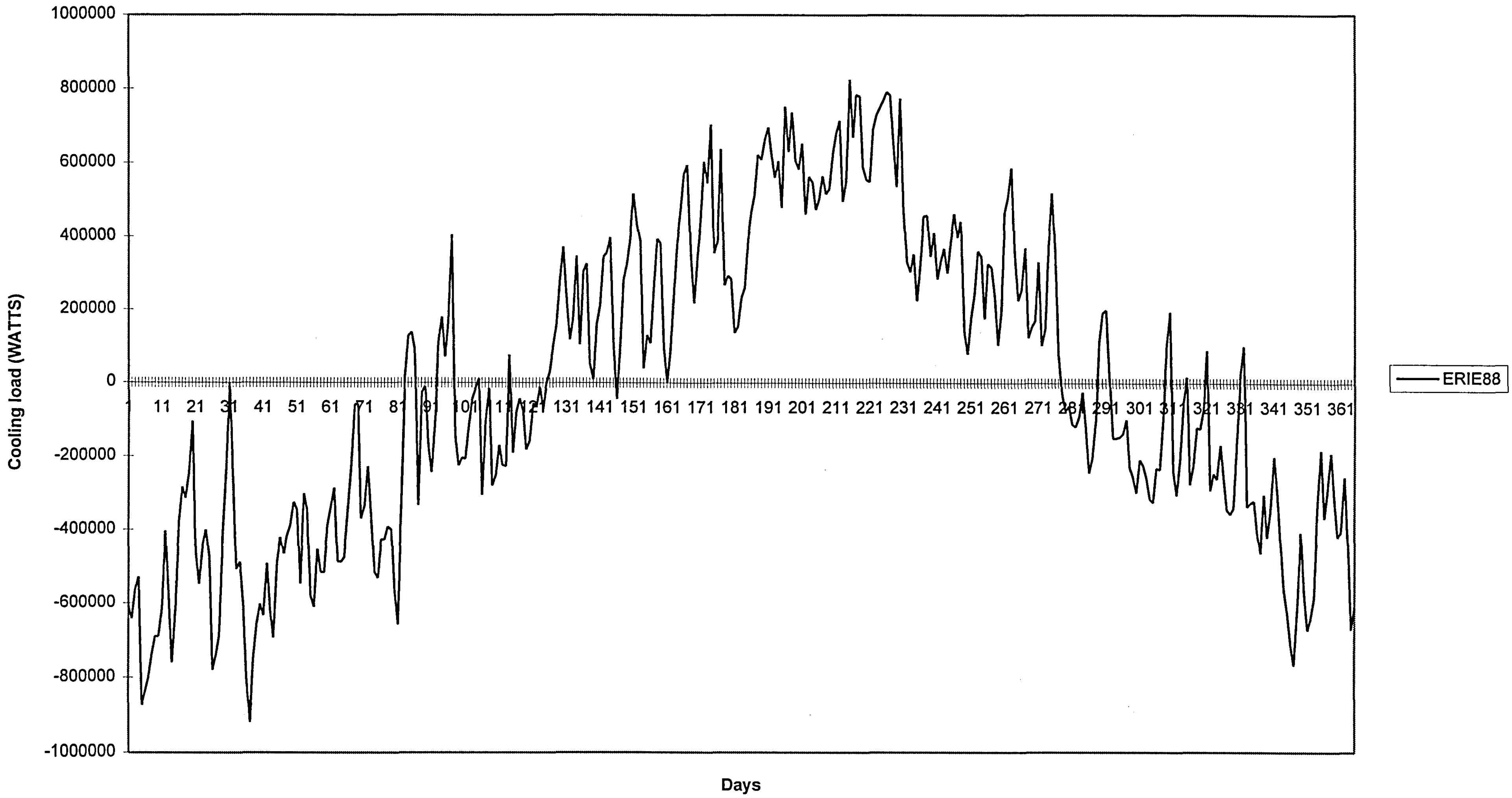


Figure -3- Cooling load for a specified building in Bristol 1986 at latitude 48 degrees north

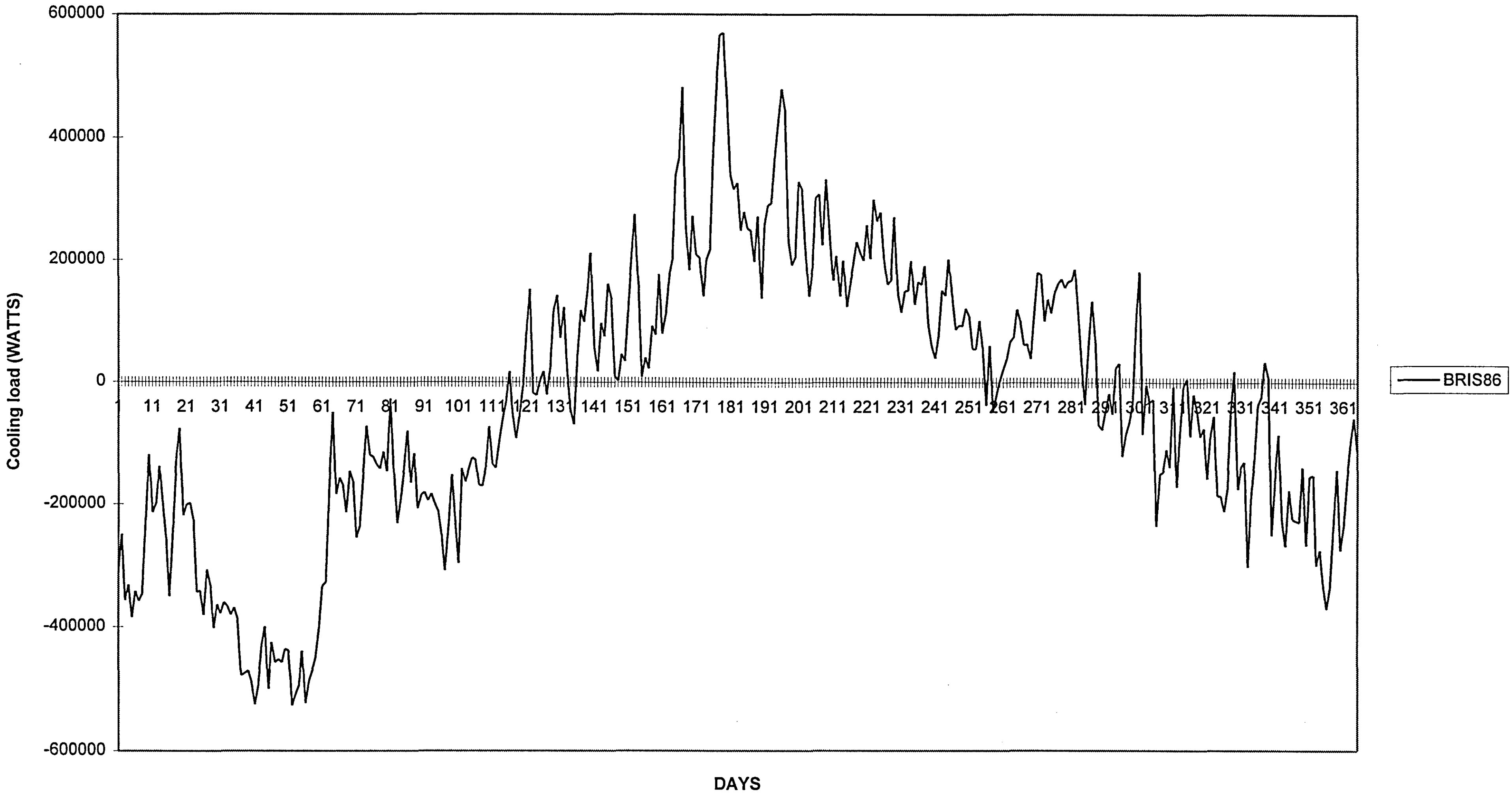


Figure -4- Cooling load for a specified building in Dyce 1986, Scotland near Aberdeen at latitude 56 degrees north

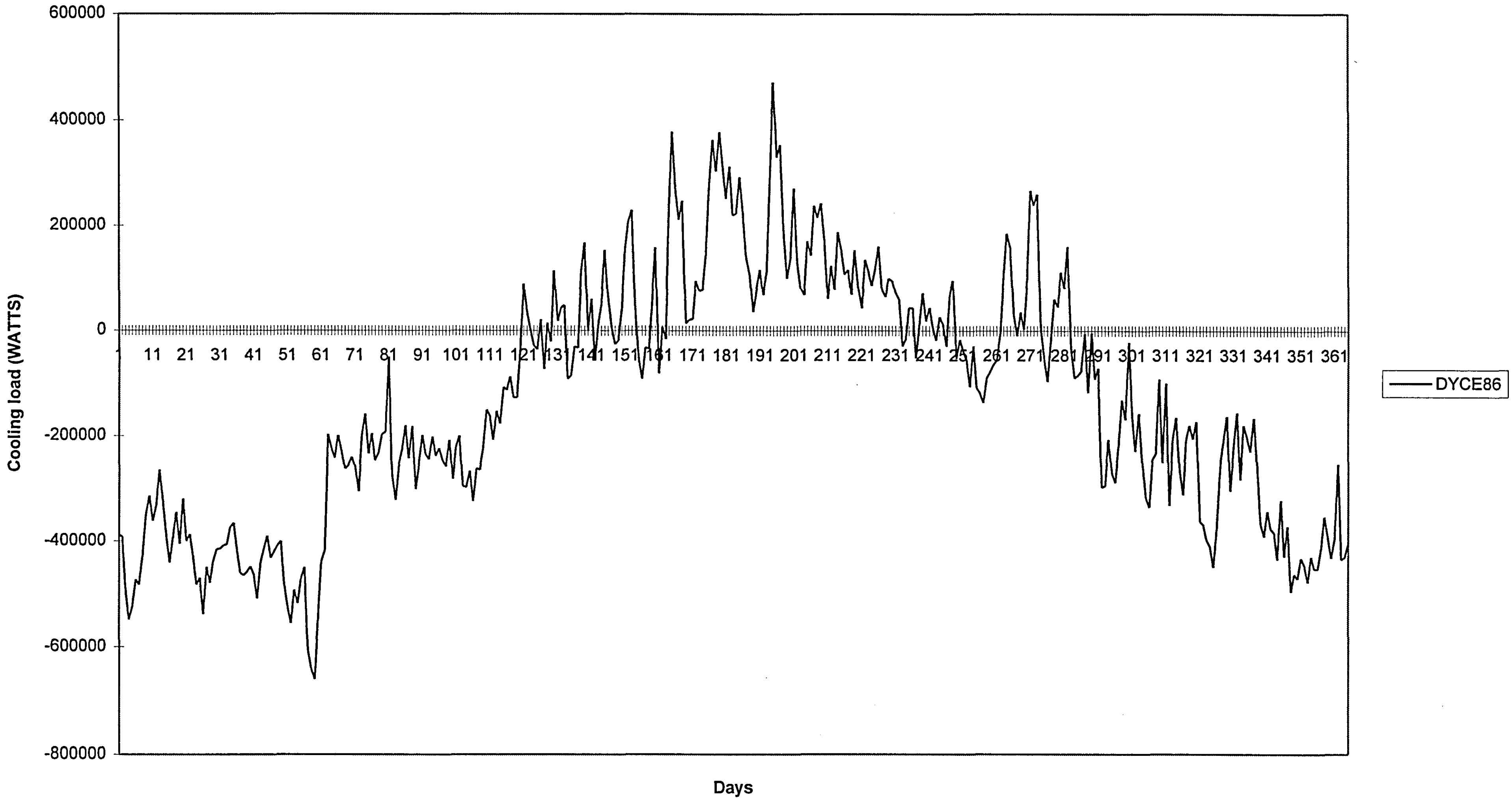


Figure -5- Cooling load for a specified building in London 1986 at latitude 48 degrees north

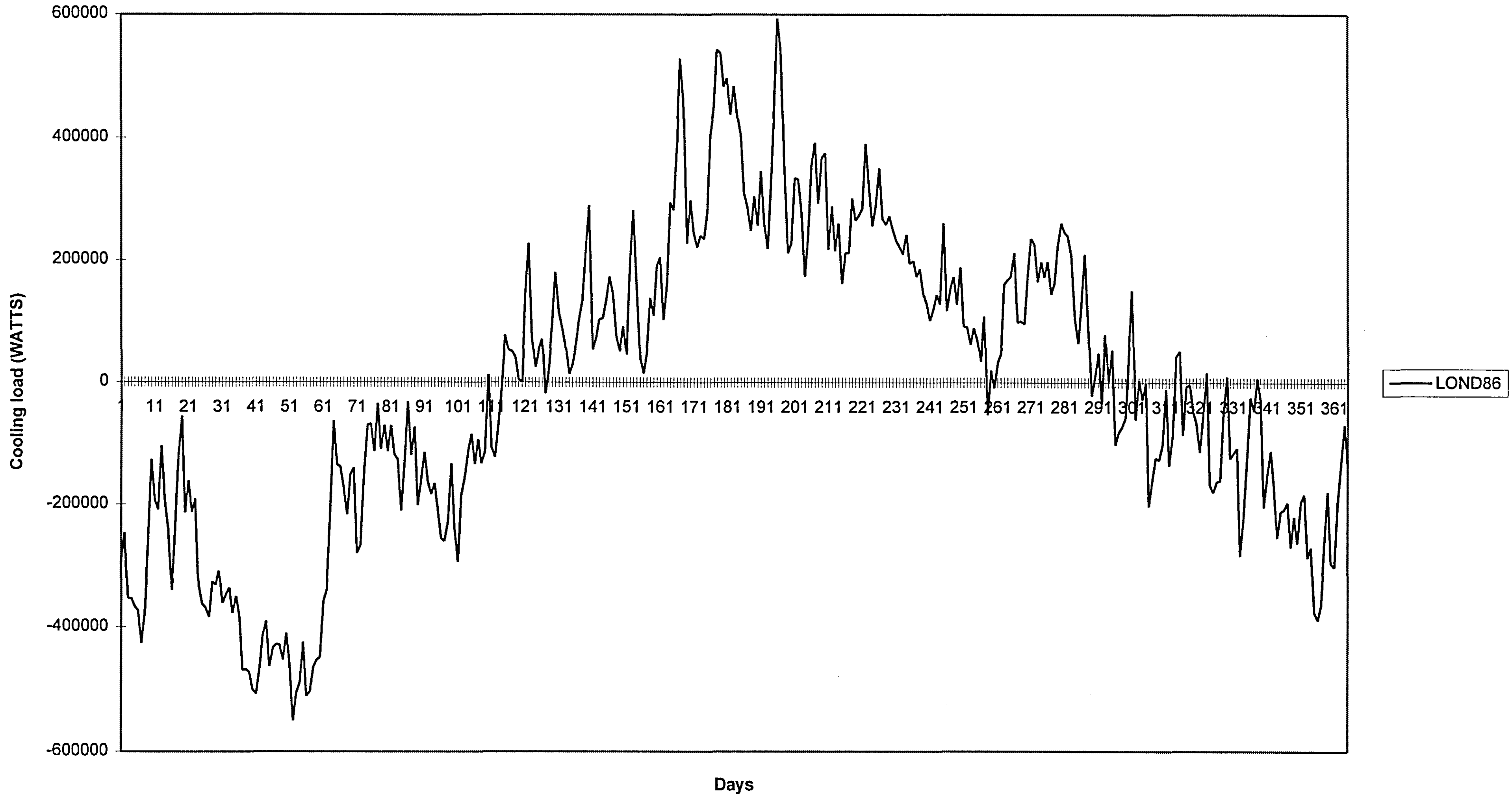


Figure -6- Cooling load for a specified building in Leeds 1986 at latitude 56 degrees north

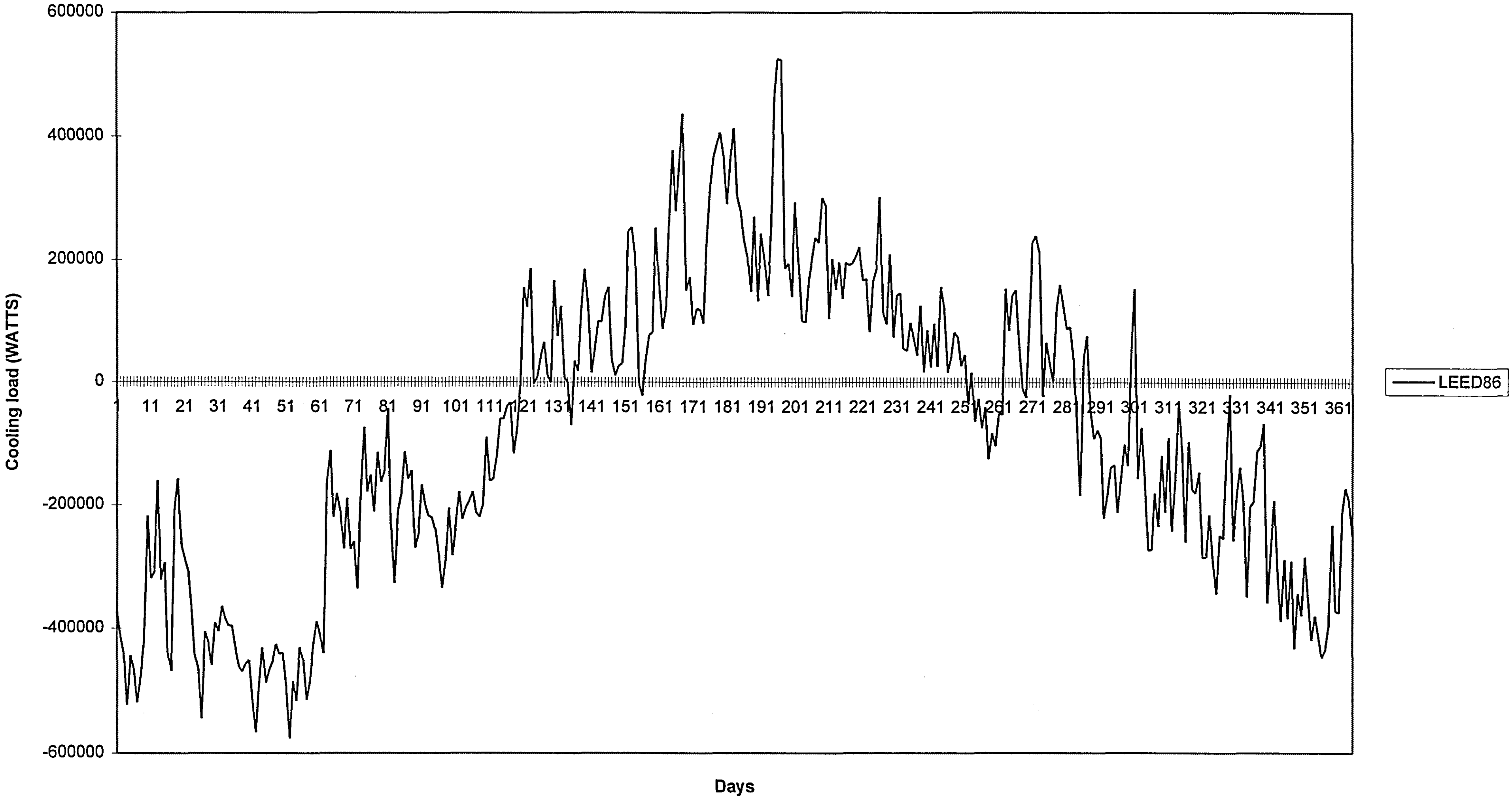


Figure -7- Cooling load for specified building in Sheffield 1986 at latitude 48 degrees north

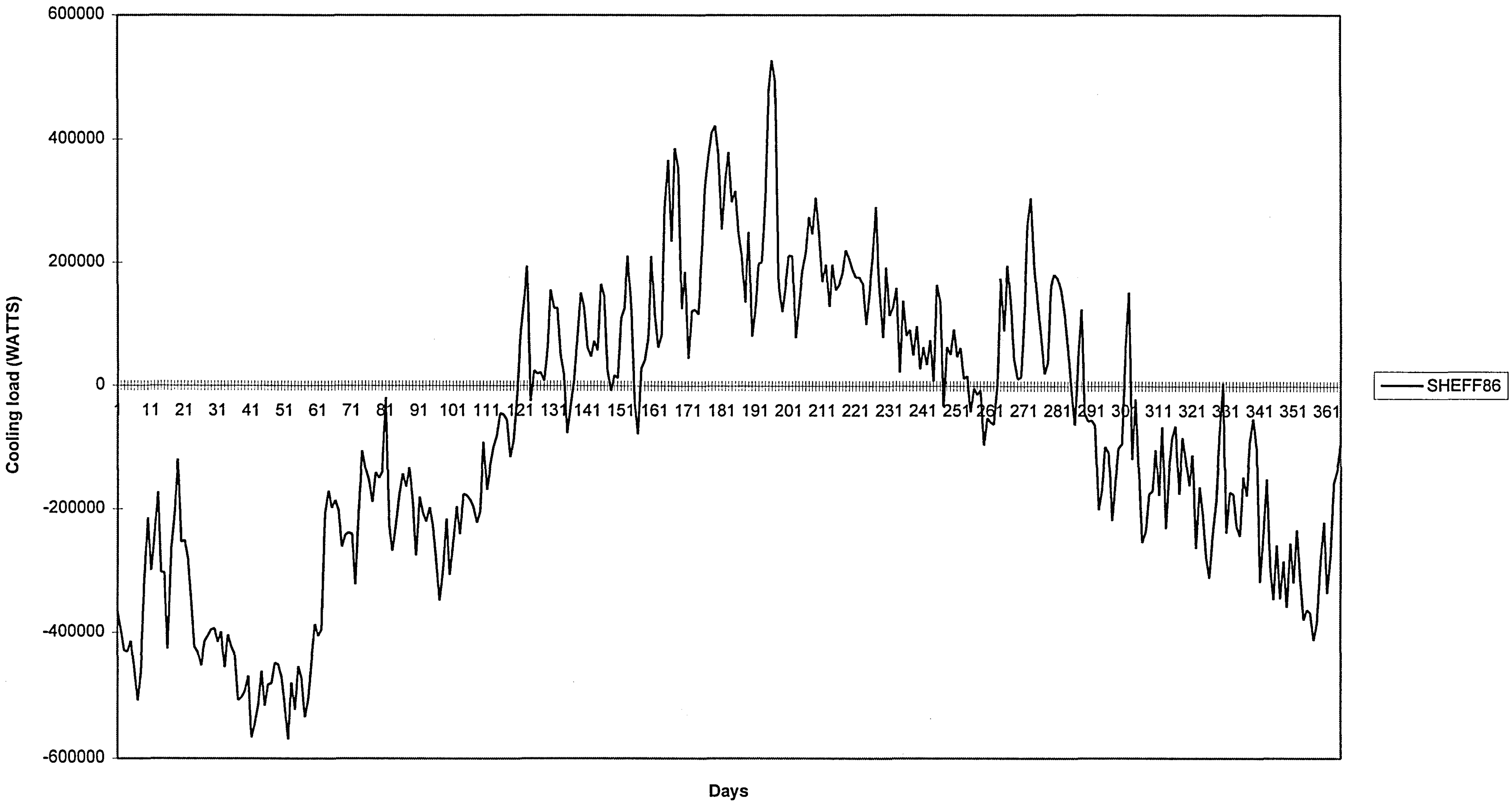


Figure -8- Cooling load for a specified building in East Kilbride1986, Scotland near Glasgow at latitude 56 degrees north

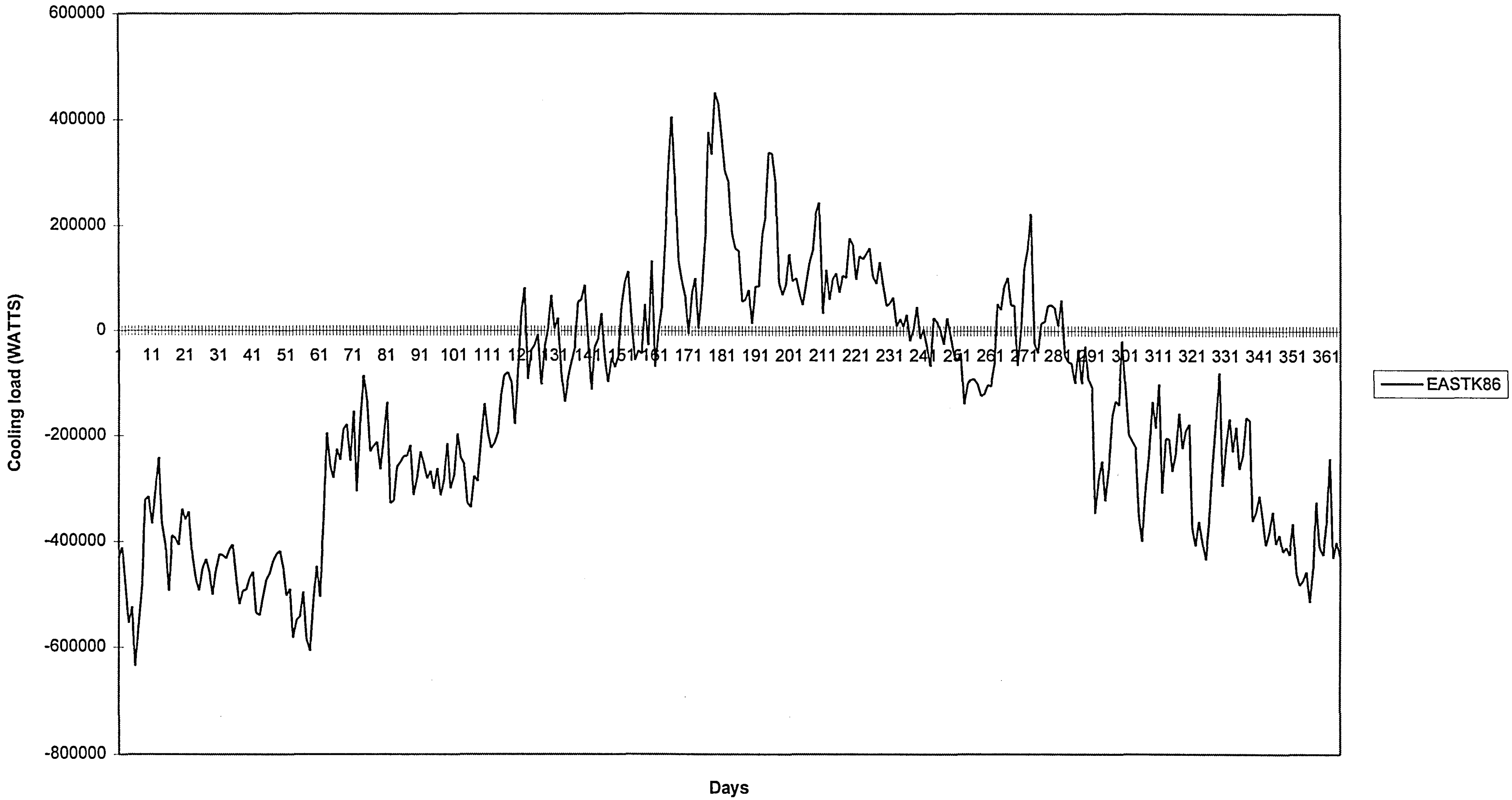


Figure -9- Cooling load for a specified building in Hull 1986 at latitude 56 degrees north

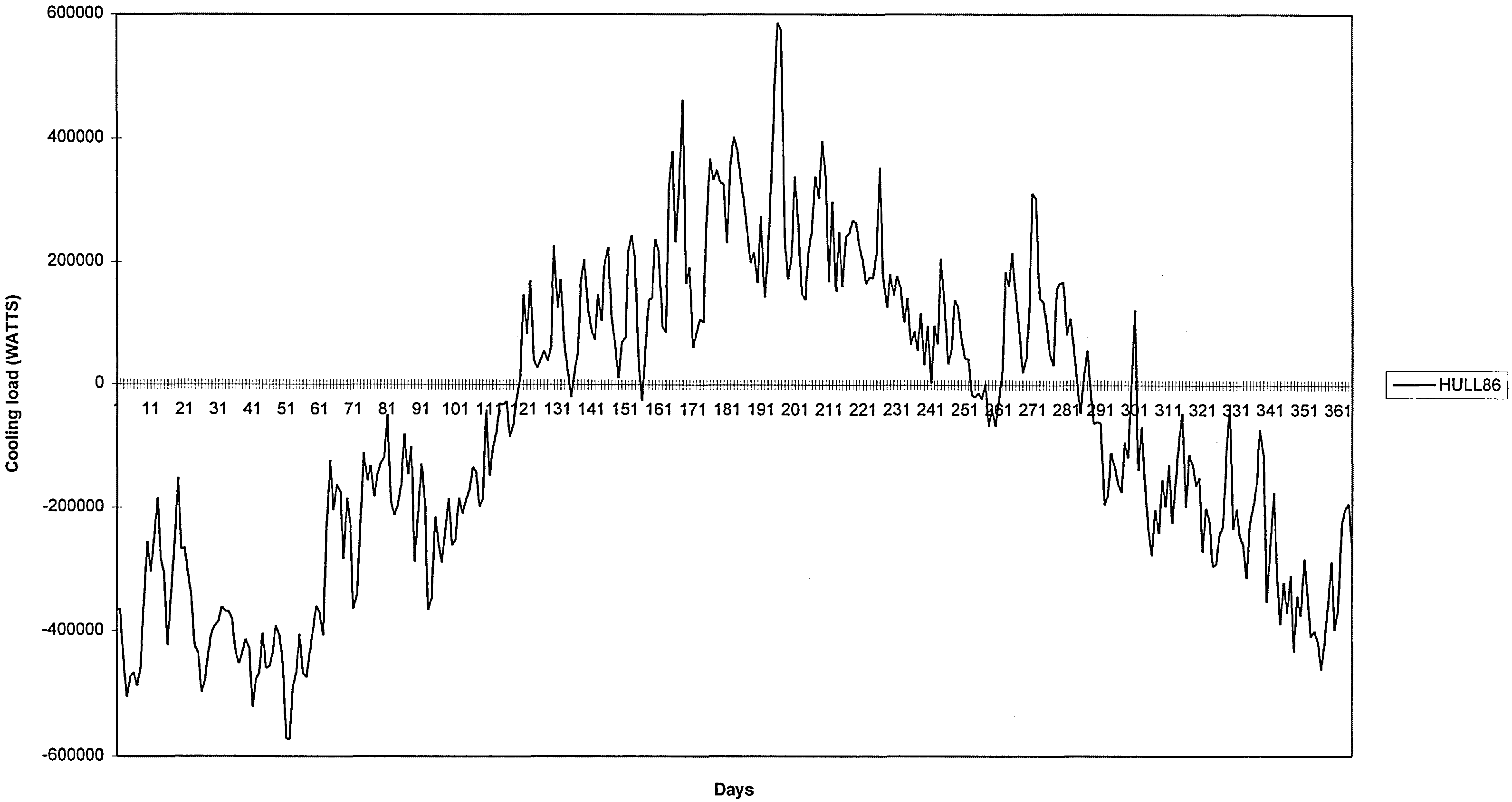


Figure -10- Cooling load for a specified building in Sheffield 1988 at latitude 48 degrees north

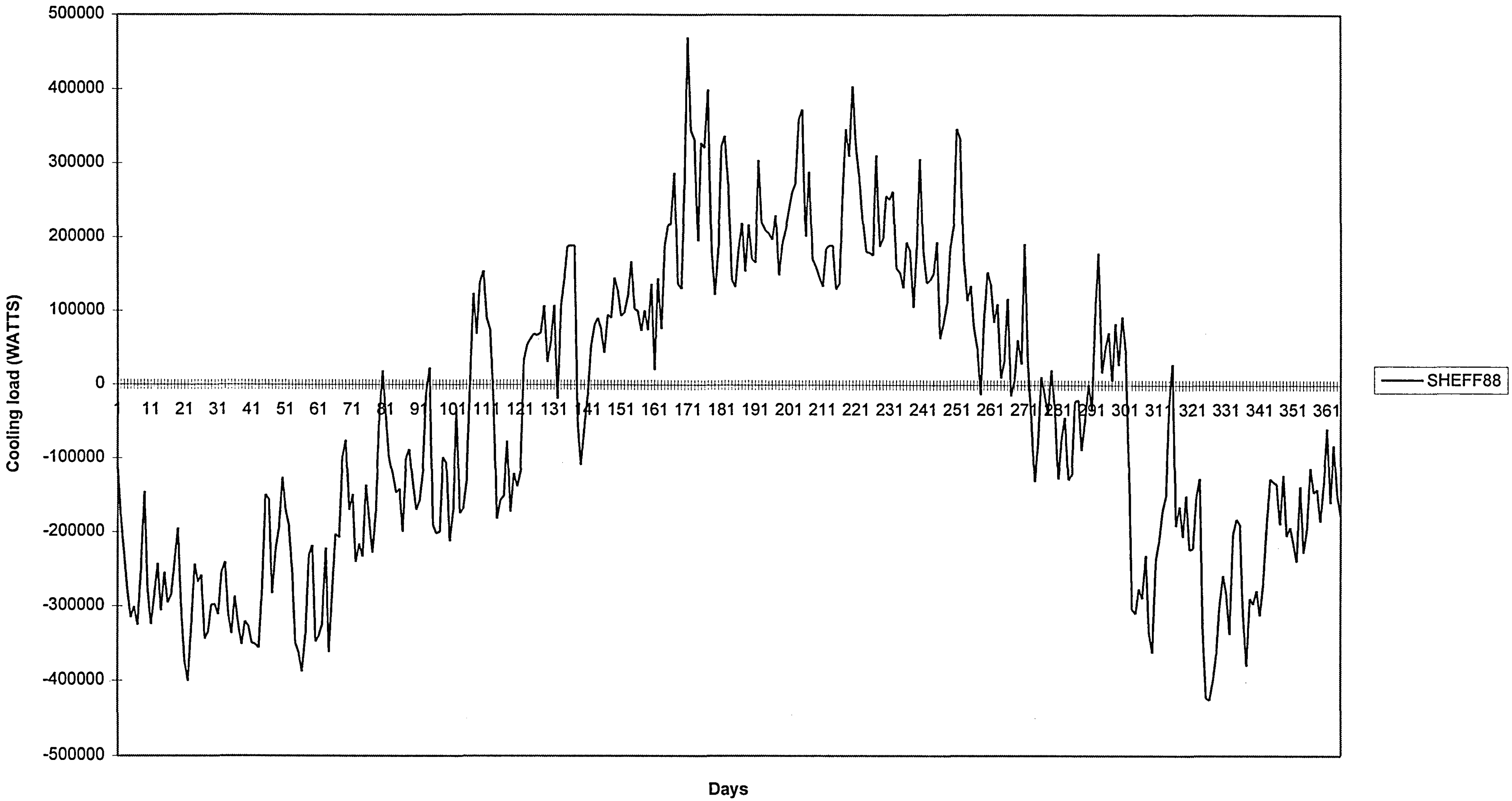


FIGURE-11-SHEFFIELD 1988 TOTAL COOLING LOAD FOR LATITUDES 40, 48, 56

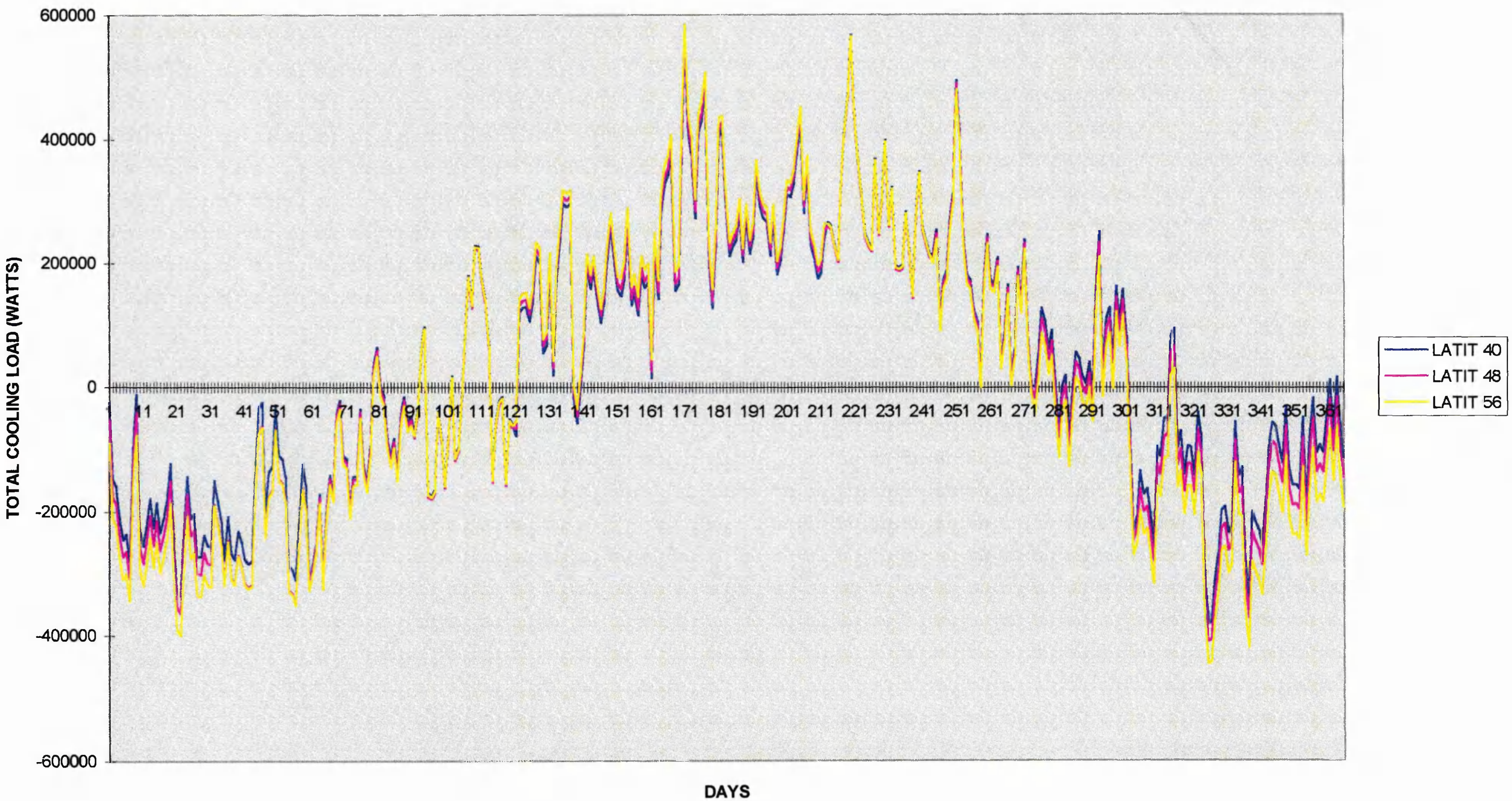


FIGURE-12- COOLING LOAD FROM ROOFS ONLY FOR A SPECIFIED BUILDING IN ERIE, USA 1988 USING DIFFERENT LATITUDES 40, 48, 56 DEGREES NORTH

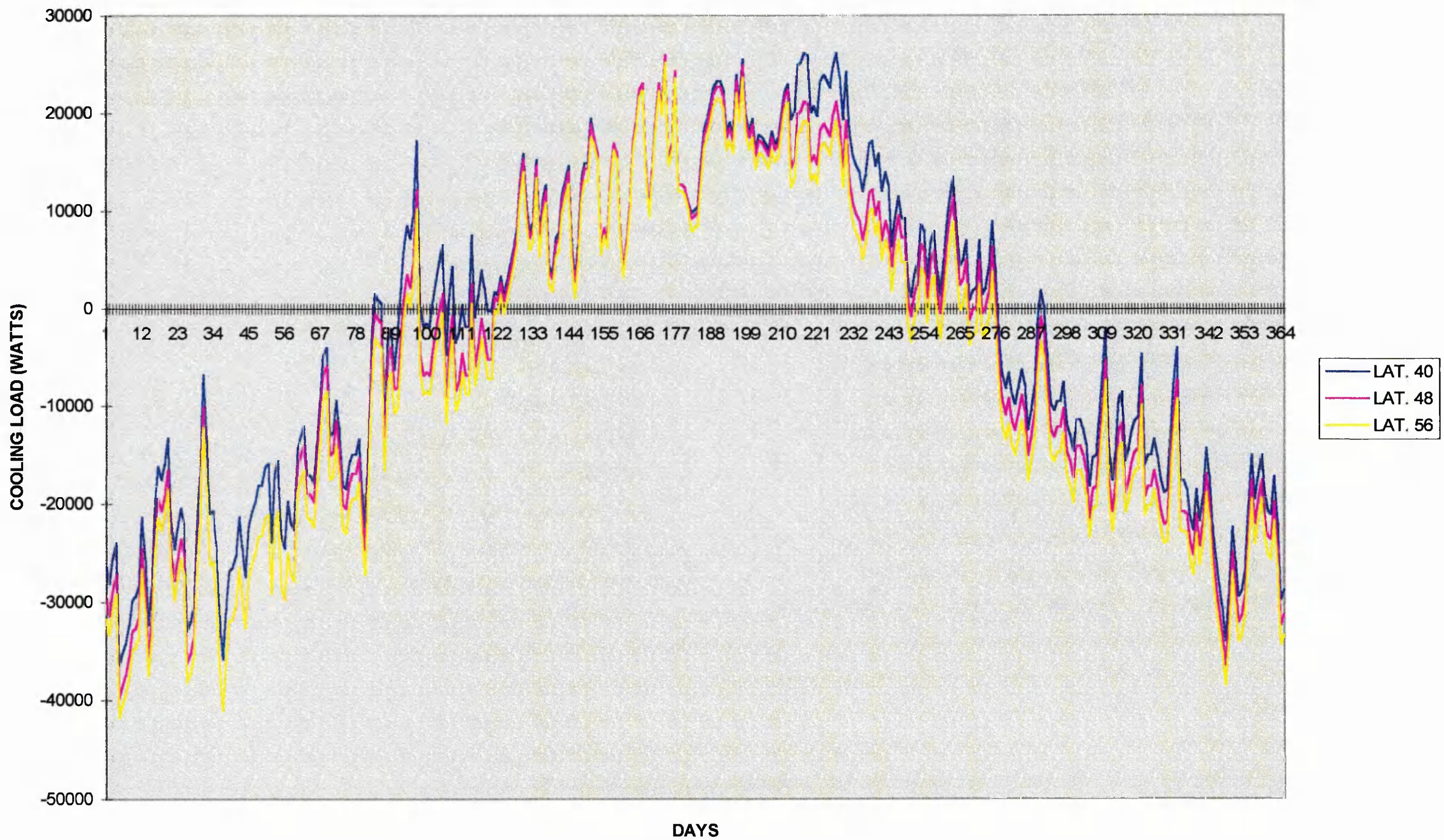


Figure -13- Cooling load for conduction load through glass at a specified building in Sheffield 1988

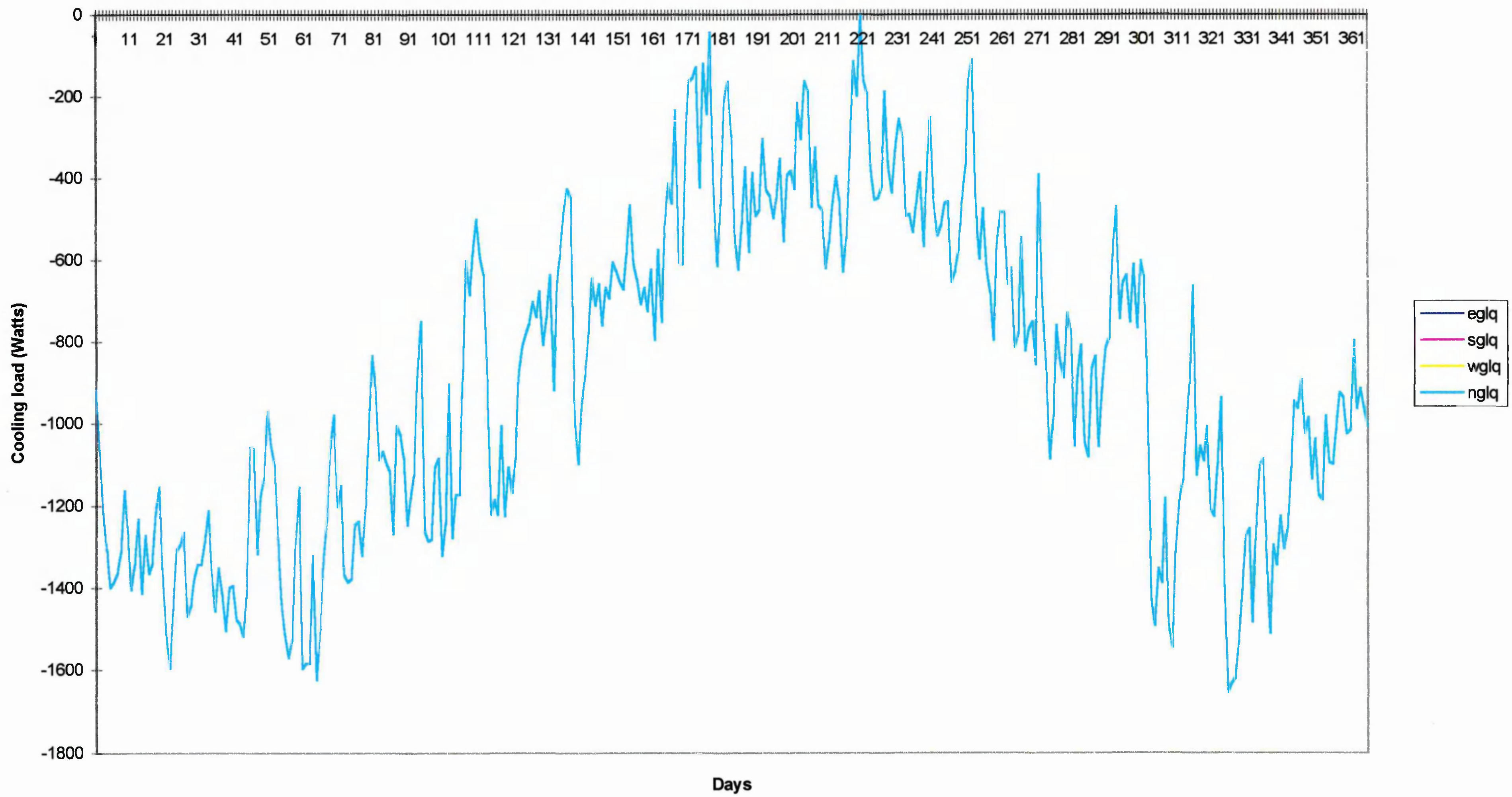


Figure -14- Maximum cooling load for walls at a specified building in Sheffield 1988

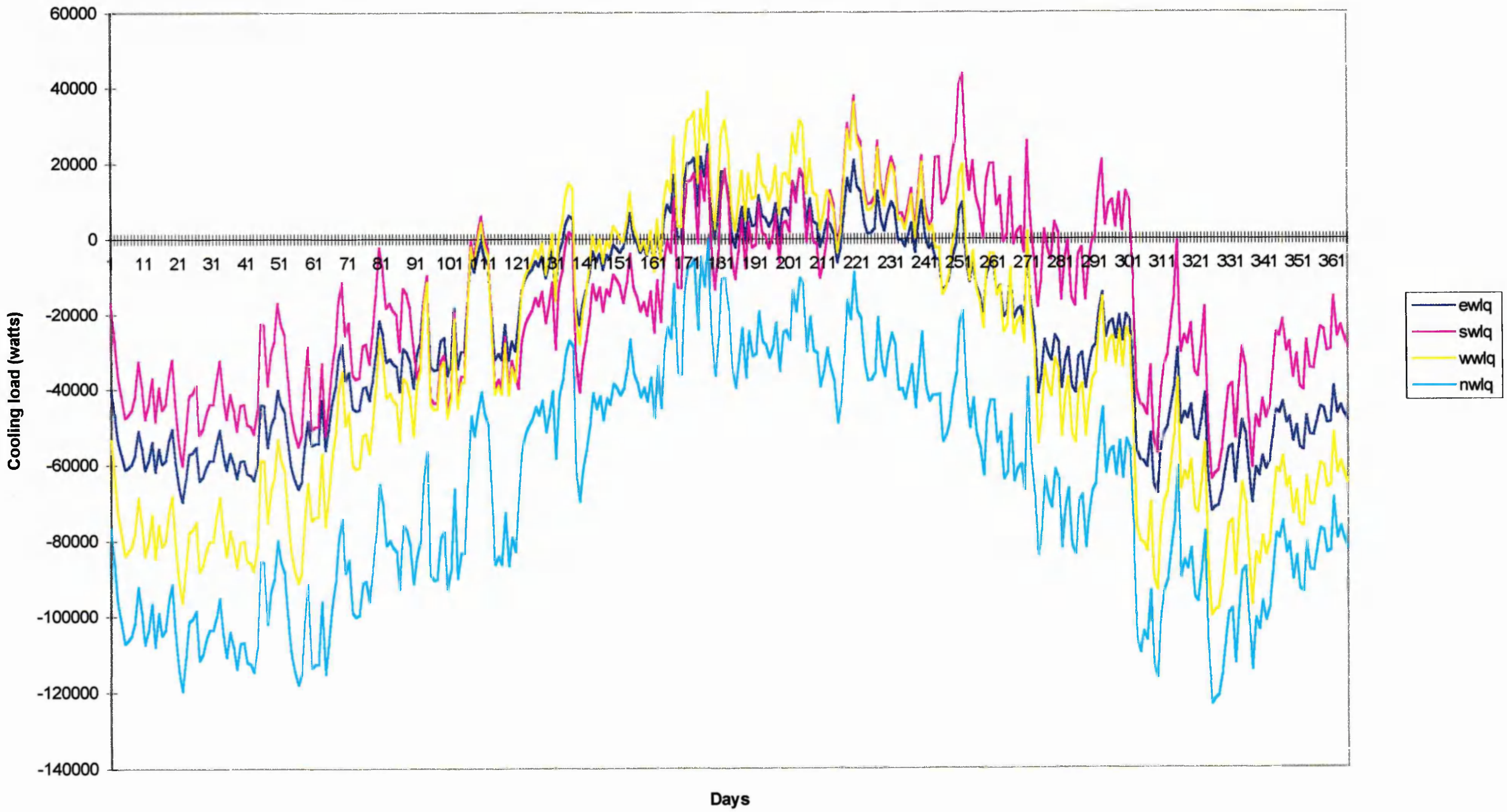


Figure -15- Latent and sensible cooling load for a specified building in Sheffield 1988

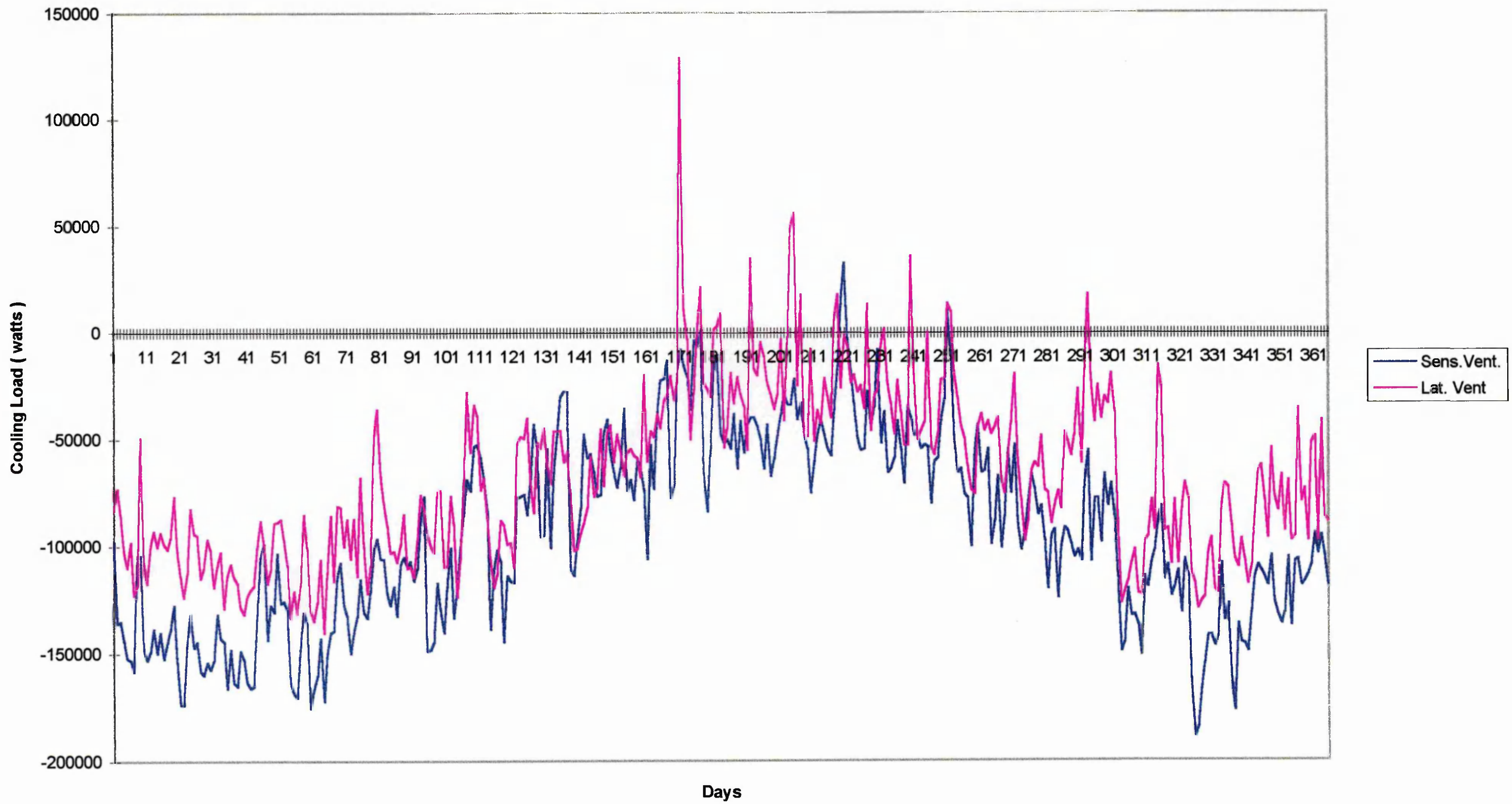


Figure -16 -Maximum Solar cooling load for a specified building in Sheffield 1988

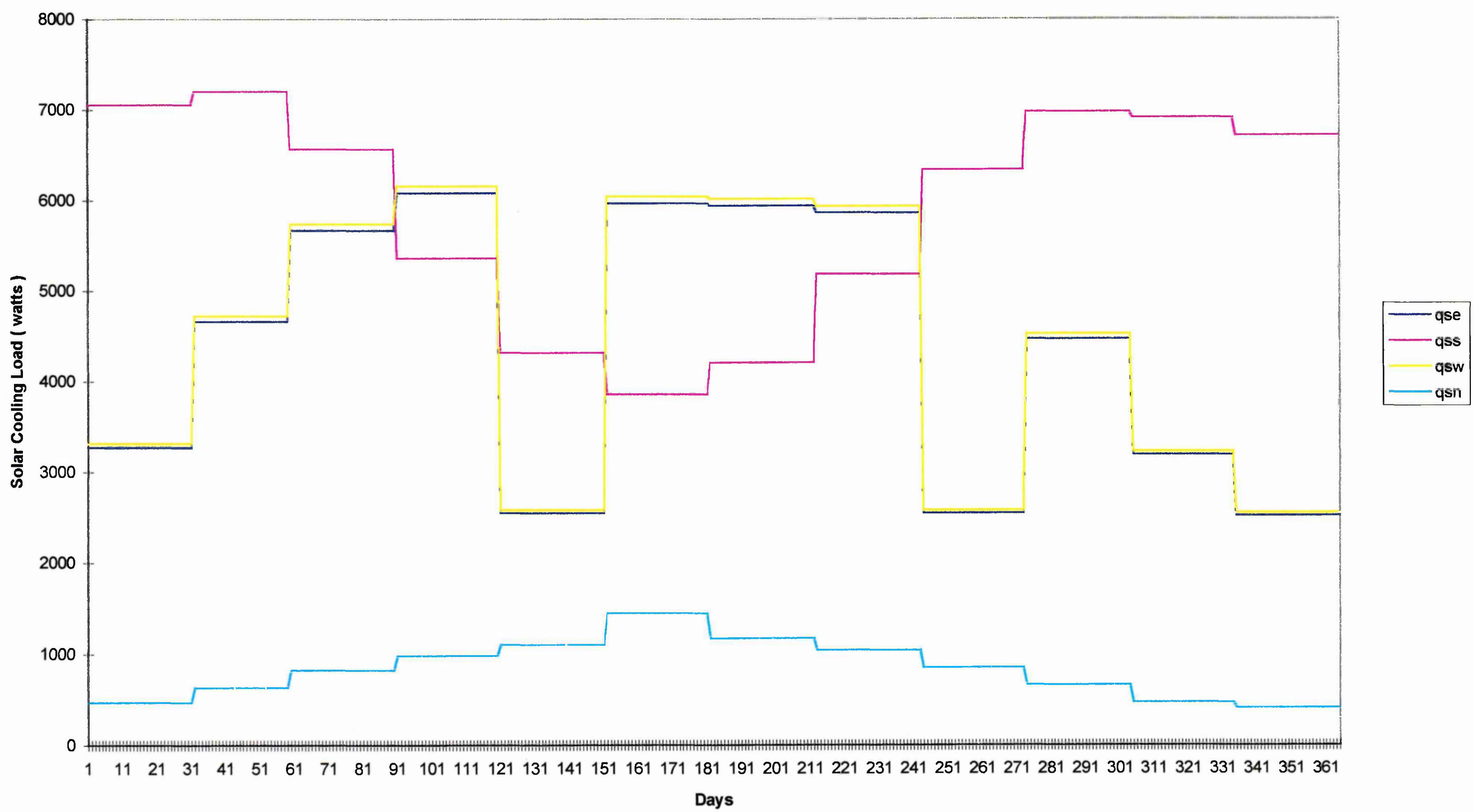


Figure 17 Maximum Solar Cooling Load for a specified building in London 1986 assuming Latitude is 40 Degree North

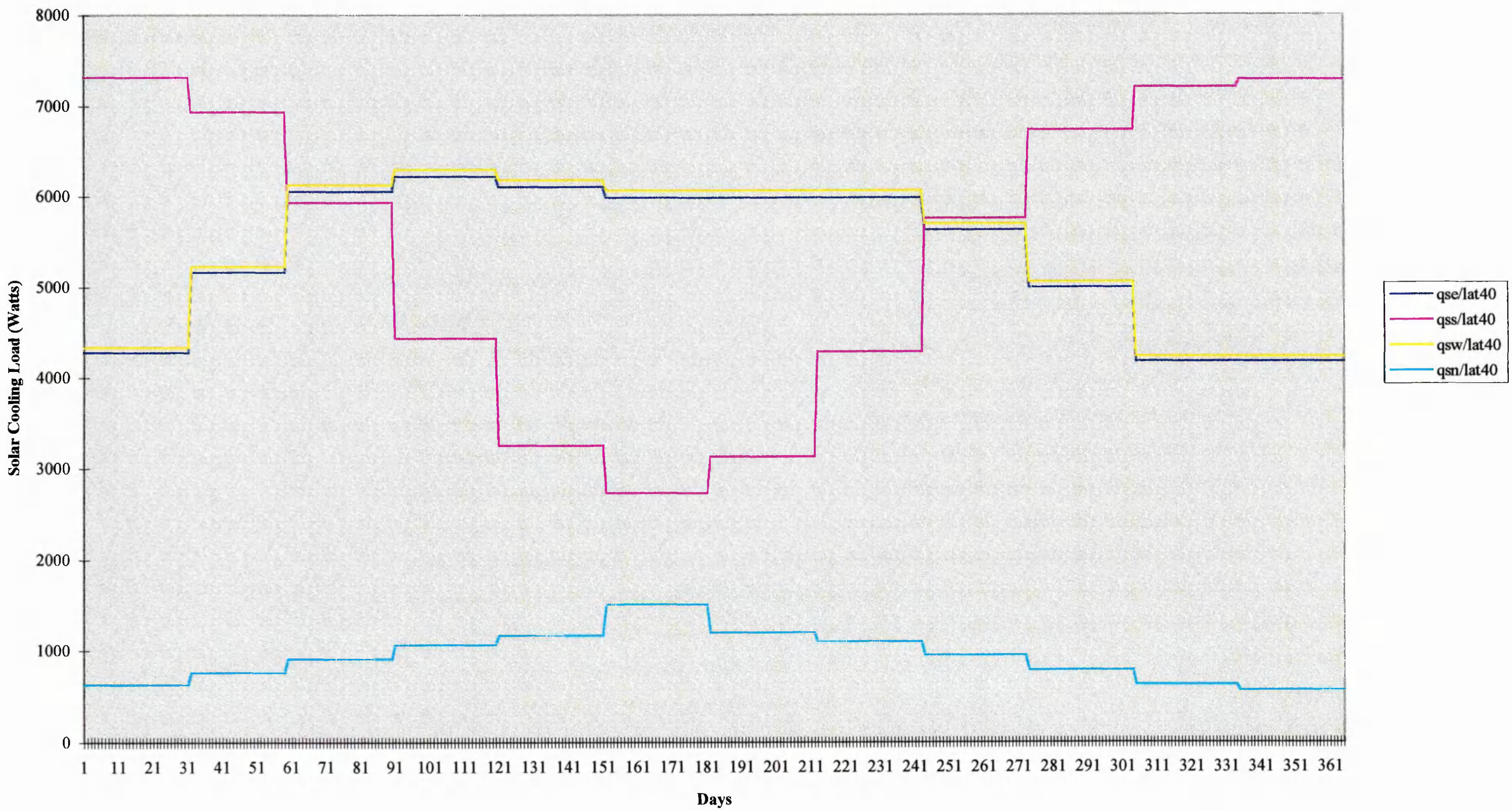


Figure-18- Maximum Solar Cooling Load for a Specified Building in London 1986 Assuming Latitude is 56 Degrees North

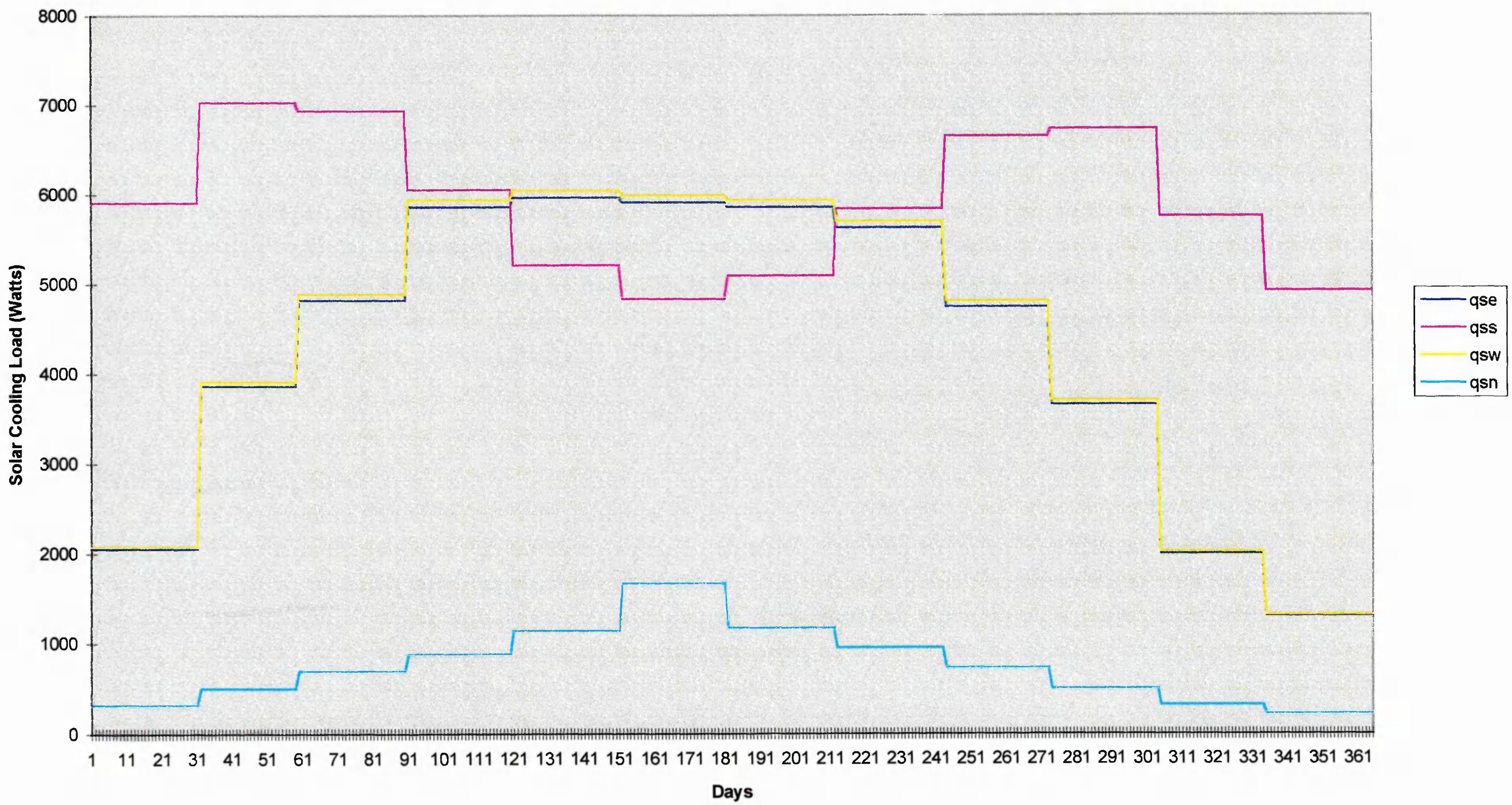


FIGURE-19- SHEFFIELD 1988 TOTAL COOLING LOAD USING DIFFERENT INDOOR DESIGN TEMPERATURE

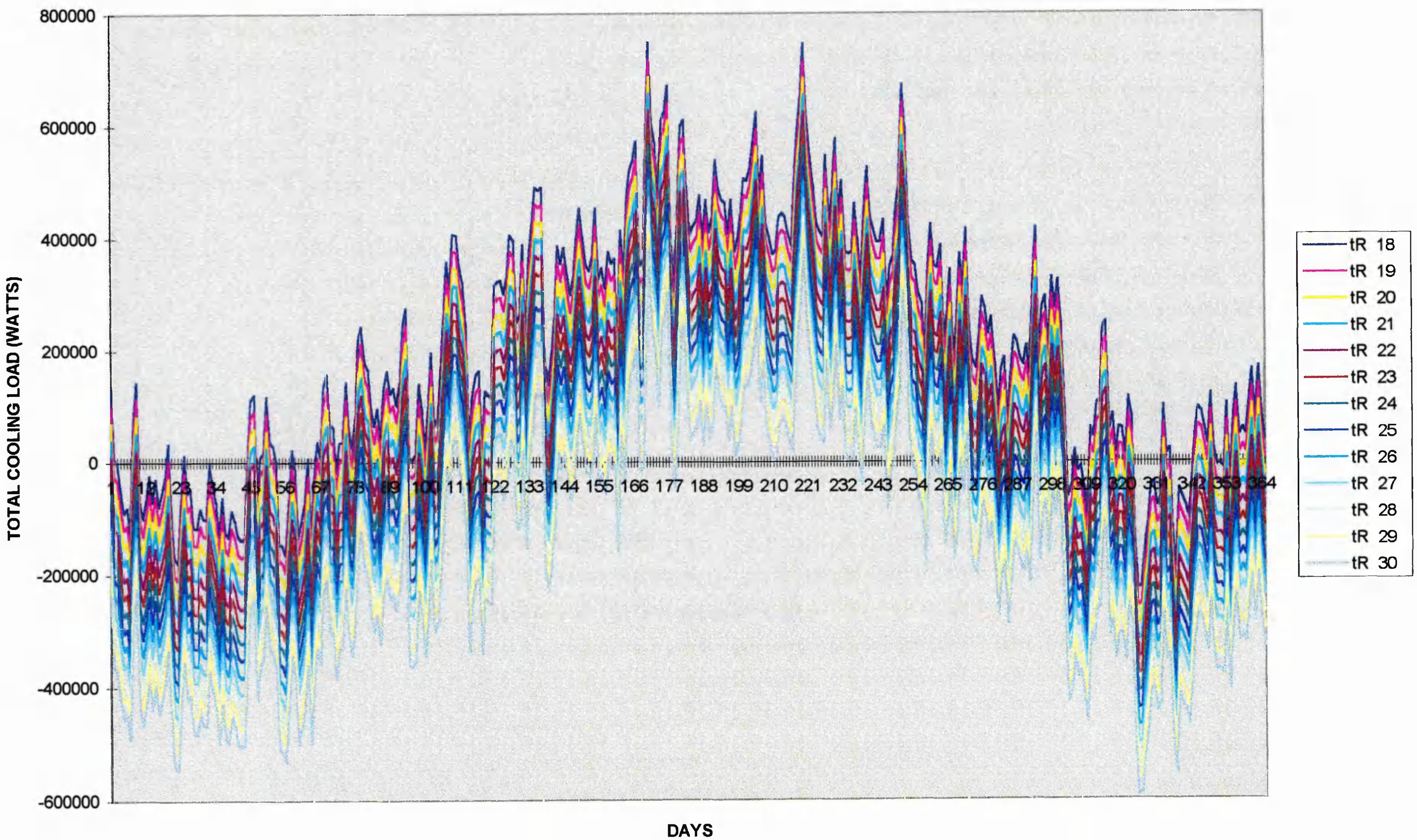


Figure -20 -Cooling Load for the same building in Bristol, Dyce and London at Latitudes 48,48 and 56 Degrees North respectivly

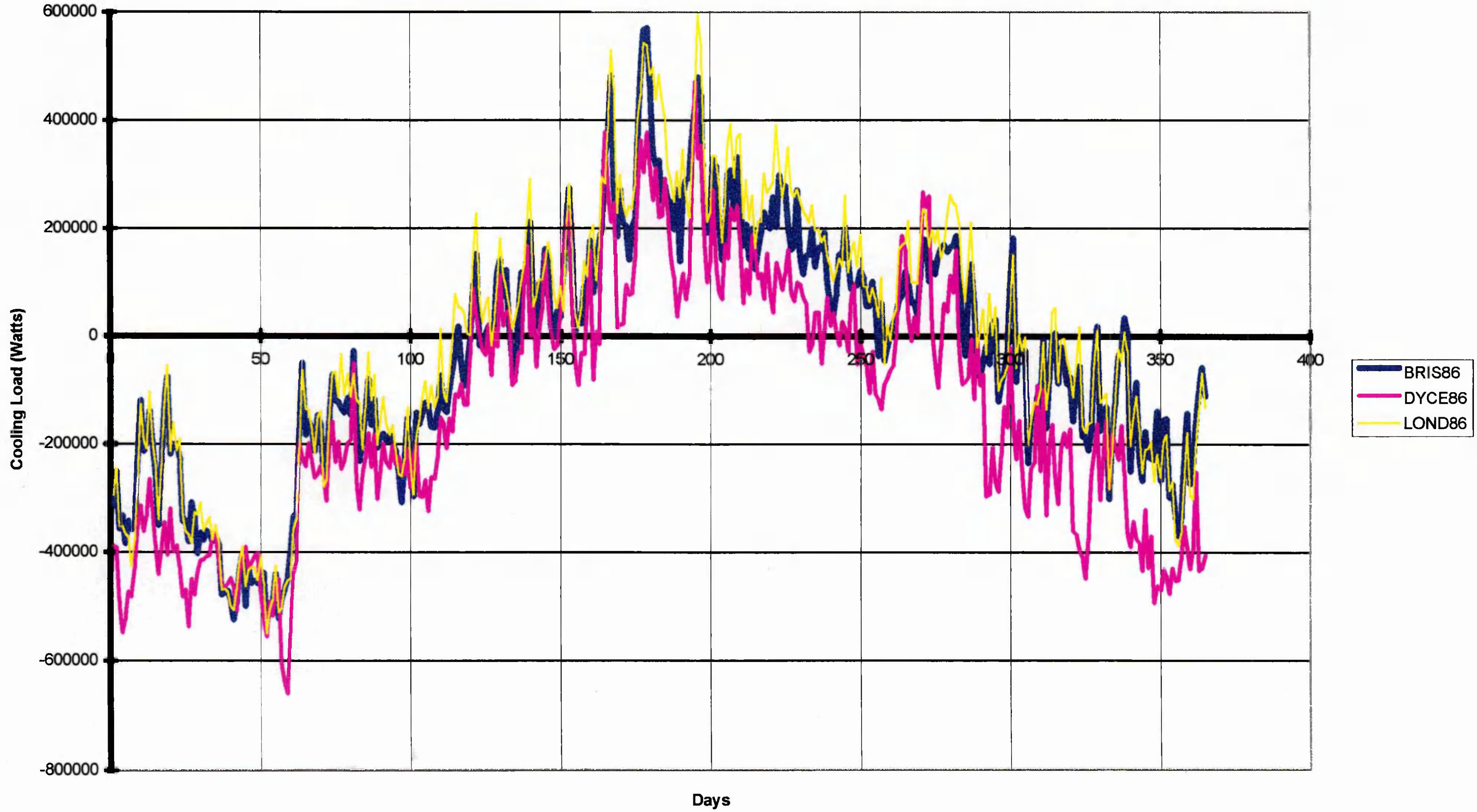


Figure-21-TOTAL COOLING LOAD FOR A SPECIFIED BUILDING IN SHEFFIELD 1988 USING DIFFERENT INDOOR DESIGN TEMPERATURES

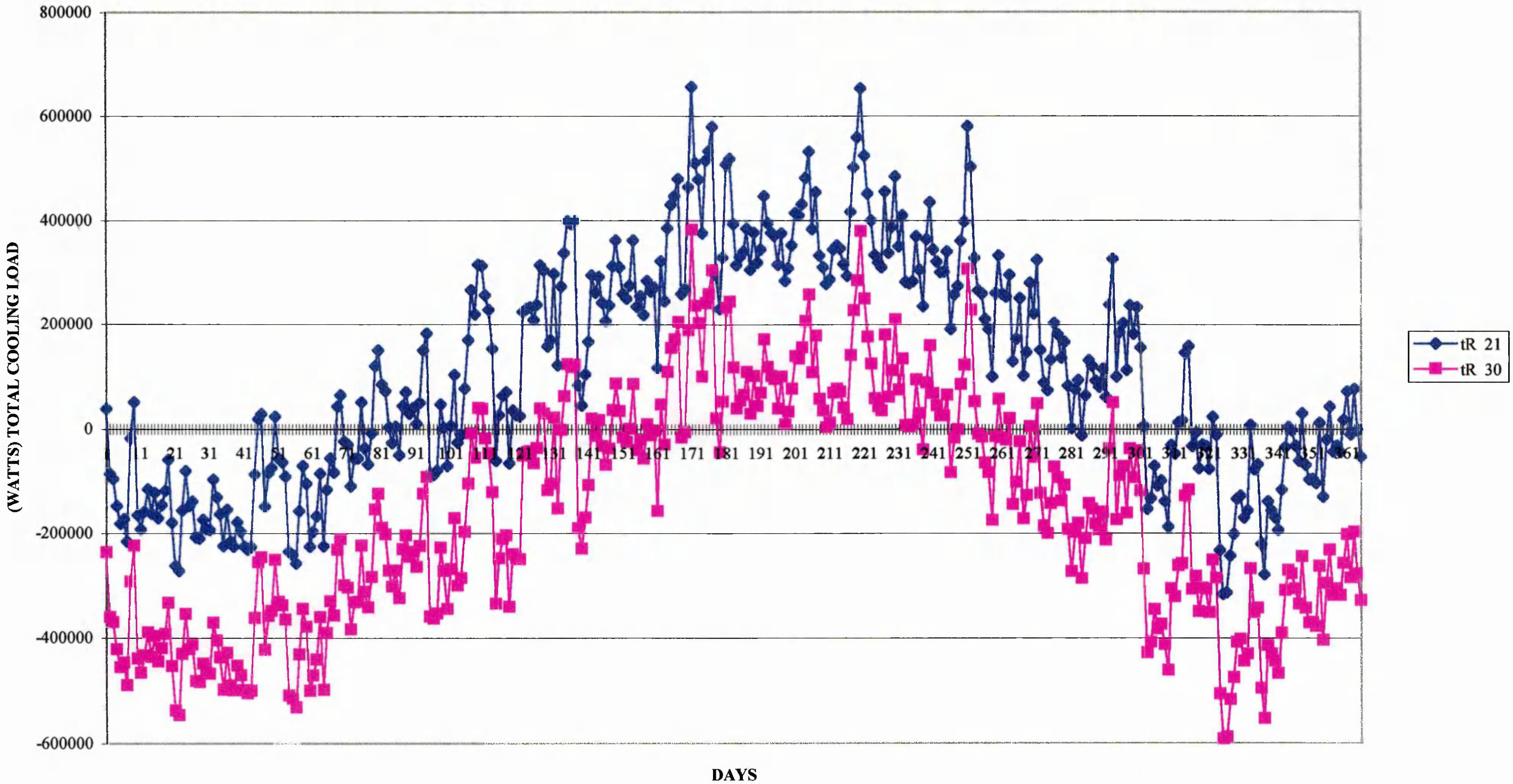
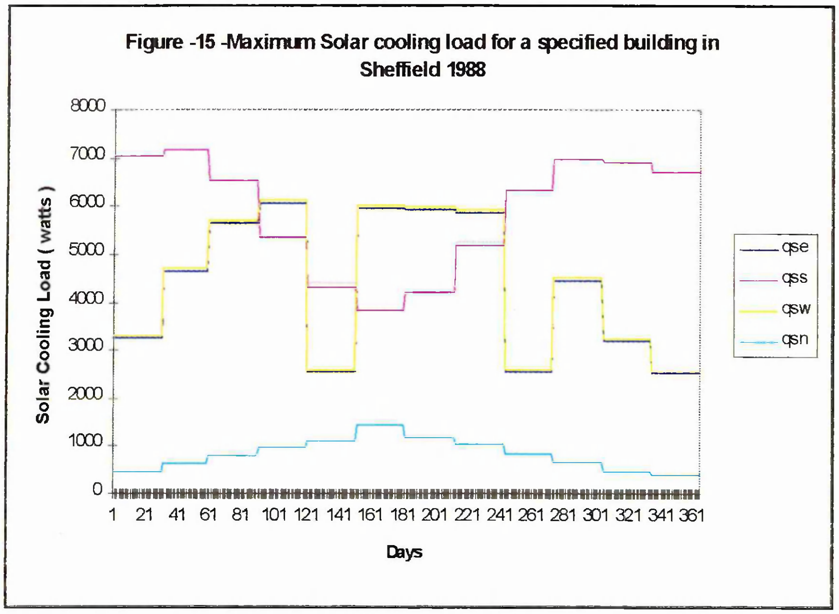
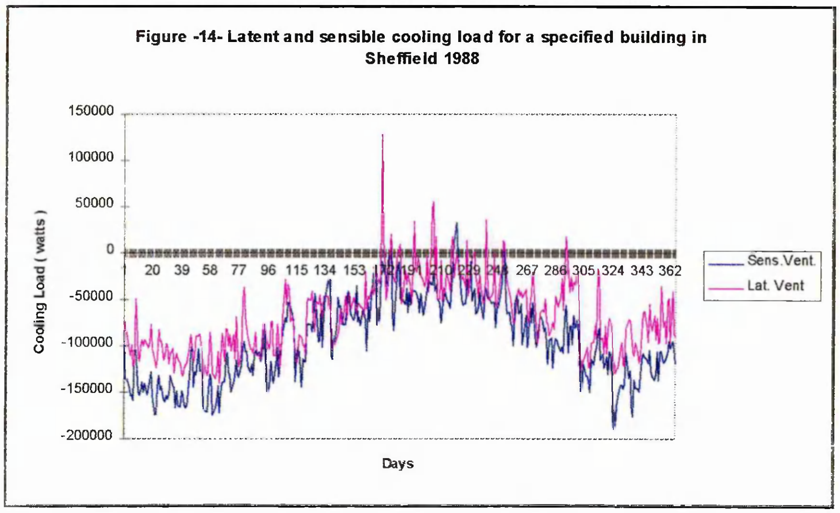


FIGURE-22-Using Different Components of the Building Cooling Load to Determine when the Peak Occurs





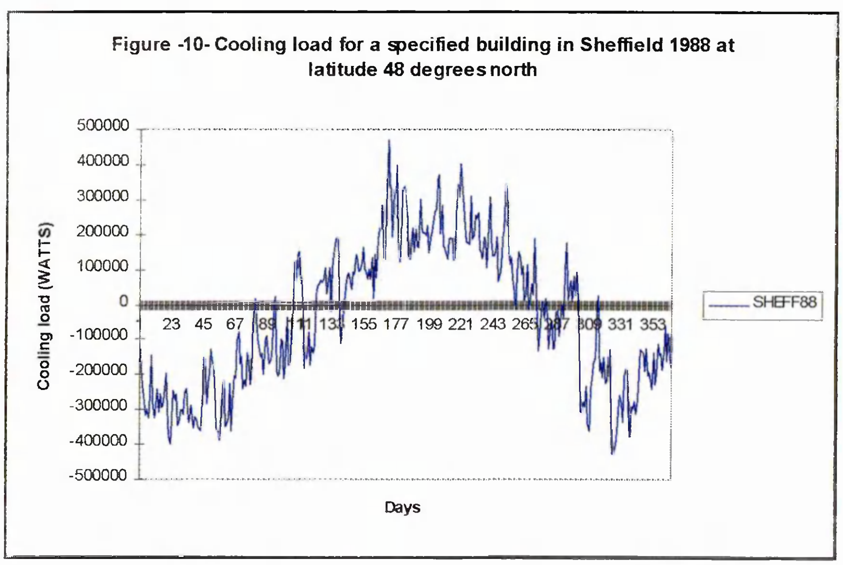
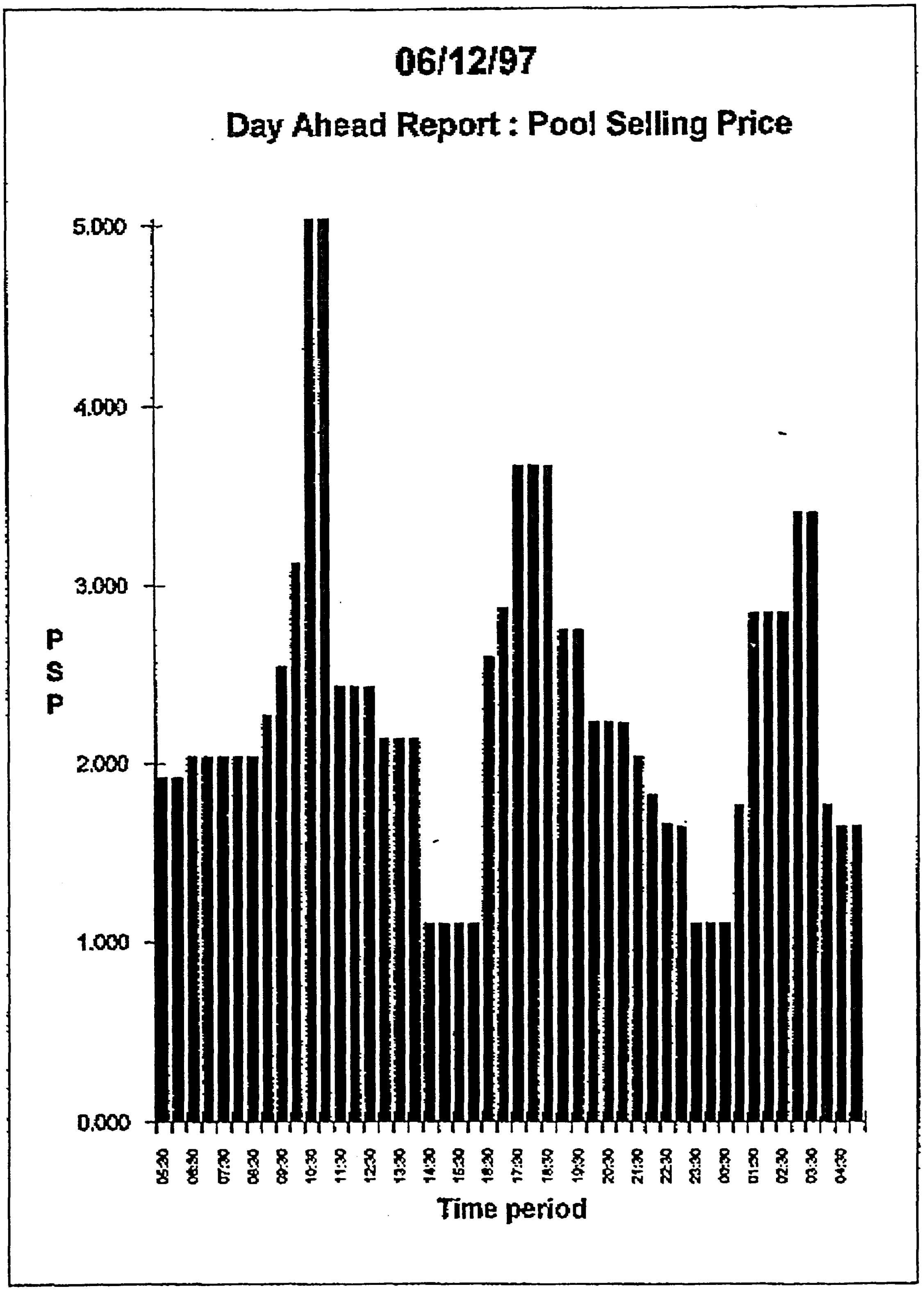


Figure 23- Day ahead report: Pool selling prices



* SMP, LOLP and PPP are provisional
** FORECAST PSP includes YE forecast of Uplift and Transmission Services U.O.S. charges
*** Final Prices do not currently include the Transmission Services U.O.S. Charge

Appendix D

Cooling Load Formulas

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<u>The equations that have been used to form the program</u>

<u>EXTERNAL</u>

<u>Solar Load</u>

The orientation included is east, west, north, and south

q = A(SC)(SHGF)(CLF)

A = area calculated from building plans
SC = shading coefficients
SHGF = maximum solar heat gain by orientation, latitude, and month.
CLF = cooling load with/without shade by orientation

<u>Roof</u>

q = U (A)(CLTD)
U = roof design heat transfer coefficient
A = area calculated from building plans
CLTD = cooling load temperature difference with /without suspended ceiling, there are 26 types for flat roofs has been entered in the program as a matrix as external file.

<u>The cltd has to be corrected as follows</u>

CLTDcorr = [(cltd + LM) * K + (25.5 - tR) + (to - 29.4)] * f

LM = cltd correction for latitude and month
K = colour adjustment factor
=1 if dark coloured or light in an industrial area
= .5 if permanently light-coloured (rural area)
(25.5 - tR) = indoor design temperature correction
(to - 29.5) = outdoor design temperature correction, where to is the average outside temperature on design day
f = 1.0 no attic or ducts
f = 0.75 positive ventilation

Walls

The orientation included is east, west, north, and south

q = U(A)(CLTD)
U = wall design heat transfer coefficient
A = area calculated from building plans
CLTD = cooling load temperature difference

The cltd has to be corrected as follows

CLTDcorr = [(cltd + LM) * K + (25.5 - tR) + (to - 29.4)]

CLTD = cooling load temperature difference
LM = cltd correction for latitude and month
K = colour adjustment factor
= 1.0 if dark coloured or light in an industrial area
= 0.83 if permanently medium coloured (rural area)
= 0.65 if permanently light coloured (rural area)
colours:
light = cream
Medium = medium blue, medium green, bright red, light brown, unpainted wood, and natural colour concrete.
Dark = Dark blue, red, brown and green

(25.5 - tR) = indoor design temperature correction
(to - 29.5) = outdoor design temperature correction, where to is the average outside temperature on design day

Converting the Relative humidity (Hum%) to Absolute Humidity (W)

Patm = 1013.25
pws = 6.108 * Exp(17.245 x t) / (237.3 + t)
pw = hum * pws/100
w = .622 * pw /(patm - pw)

That involved data for 365 days to include minimum temperature, maximum temperature, relative humidity, and temperature when RH was taken

Conduction from glass

The orientation included is east, west, north, and south

$q_{conduction}$ = UA(CLTD)

U = design heat transfer coefficient
CLTD = cooling load temperature difference
A = area calculated from building plans

<u>The cltd has to be corrected as follows</u>

CLTD correct = cltd + (25.5 - tR) - (29.4 - Todave)

(25.5 - tR) = correction for room air temperature
(29.4 - Todave) = correction for outdoor daily average temperature
cltd = is selected from the matrix

INTERNAL

lights

q = (input)(CLF)

input = wattage * Fsa * usefactor
wattage = input rating from electrical plans or lighting fixture data.
Fsa = 1.2 special allowance for fluorescent
usefactor = .95
CLF = cooling load factor, light, by use schedule and hours since on from matrix.

People

$q_{sensible}$ = N(Sensible HG)(clf)

q_{latent} = N(Latent HG)

N = number of people in space
Sensible HG = 75 watt moderately active office work
Latent HG = 55 watt

Appliances

$q_{sensible\ appliances}$ = h.g. * Fu * Fr * CLFapunh *.66

.66 = sensible portion
h.g. = wattage
Fu = .5 usage factor
Fr = .32 fraction of the input energy of the hooded appliance released by radiation.
CLFapunh = cooling load factor for unhooded appliances from matrix

qla = h.g. * .34
.34 = latent portion

Power

qp = h.g.p. * CLFapunh

h.g.p = (power / (m.efficiency /100)) * Flm * Fum
m.efficiency = 81
Flm = 1 motor load factor
Fum = 1 motor use factor
CLFapunh = cooling load factor for unhooded appliances from matrix

Converting maximum and minimum temperatures into a sinusoidal wave

Tamb = (mxt - mnt)/2 +mnt + (sin(((15+n)/24) * 2* pie * -1 * (mxt -mnt)/2)

n = time
pie = 22/7
mxt = maximum outdoor temperature
mnt = minimum outdoor temperature

Ventilation & Infiltration

qsv = 1.23 * Q * dt

qsv = sensible component for the ventilation
dt = Tout-designt
designt = room design temperature
Tout = from the sinusoidal equation
Q = 7 * nop
nop = no. of people
7 L/S/person = recommended ventilation, institutional, classroom

qlv = 3010 * Q * dw
dw = Wout - Win
W = absolute humidity

Wout = from the input data for that city (kg water/kg dry air)
Win = from the corresponding design temperature

Infiltration Air / Crack Method

windows infiltration = .75 cfm/ft crack
1 cfm = 1.7 m^3/hr
therefor Window inf.=1.275 m^3/hr/ft
window inf = 4.25 m^3/hr/m crack
window inf. = 1.180555 L/S/M

finding the infiltration loss L/s on each side of the building, then selecting the greatest and compare it with one-half the sum of the infiltration on all sides of the building then use the greater value.

in this building east side window has greatest circumference value but less than one-half circumference value on all sides

qsinf = 1.23 * Qinf * dt
qlinf = 3010 *Qinf * dw

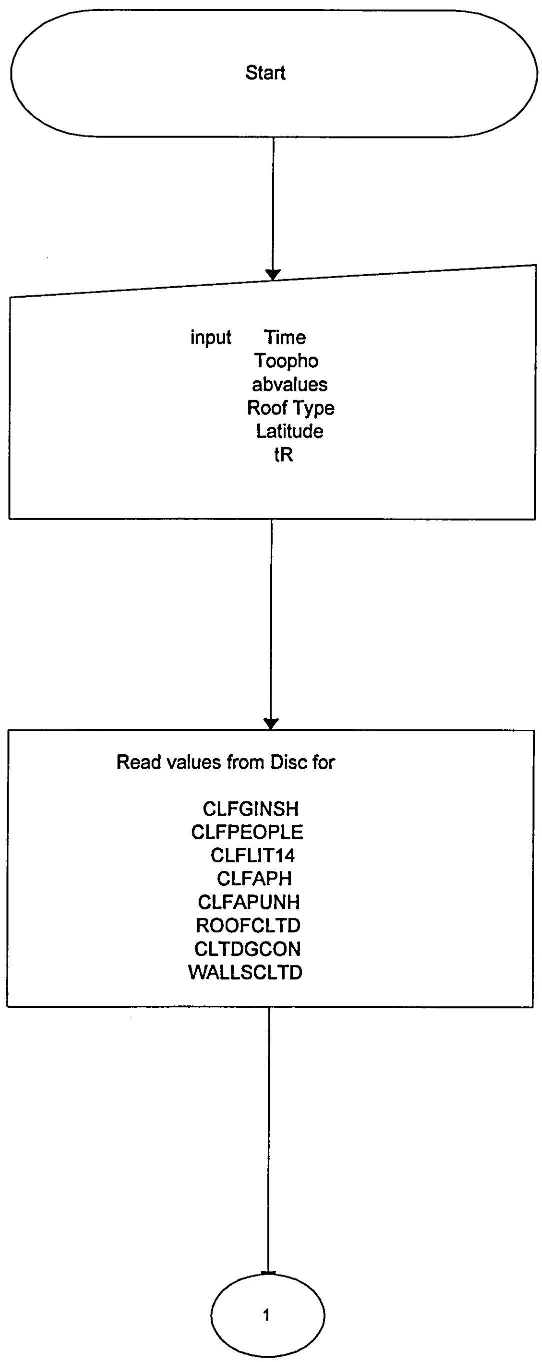
Total Q

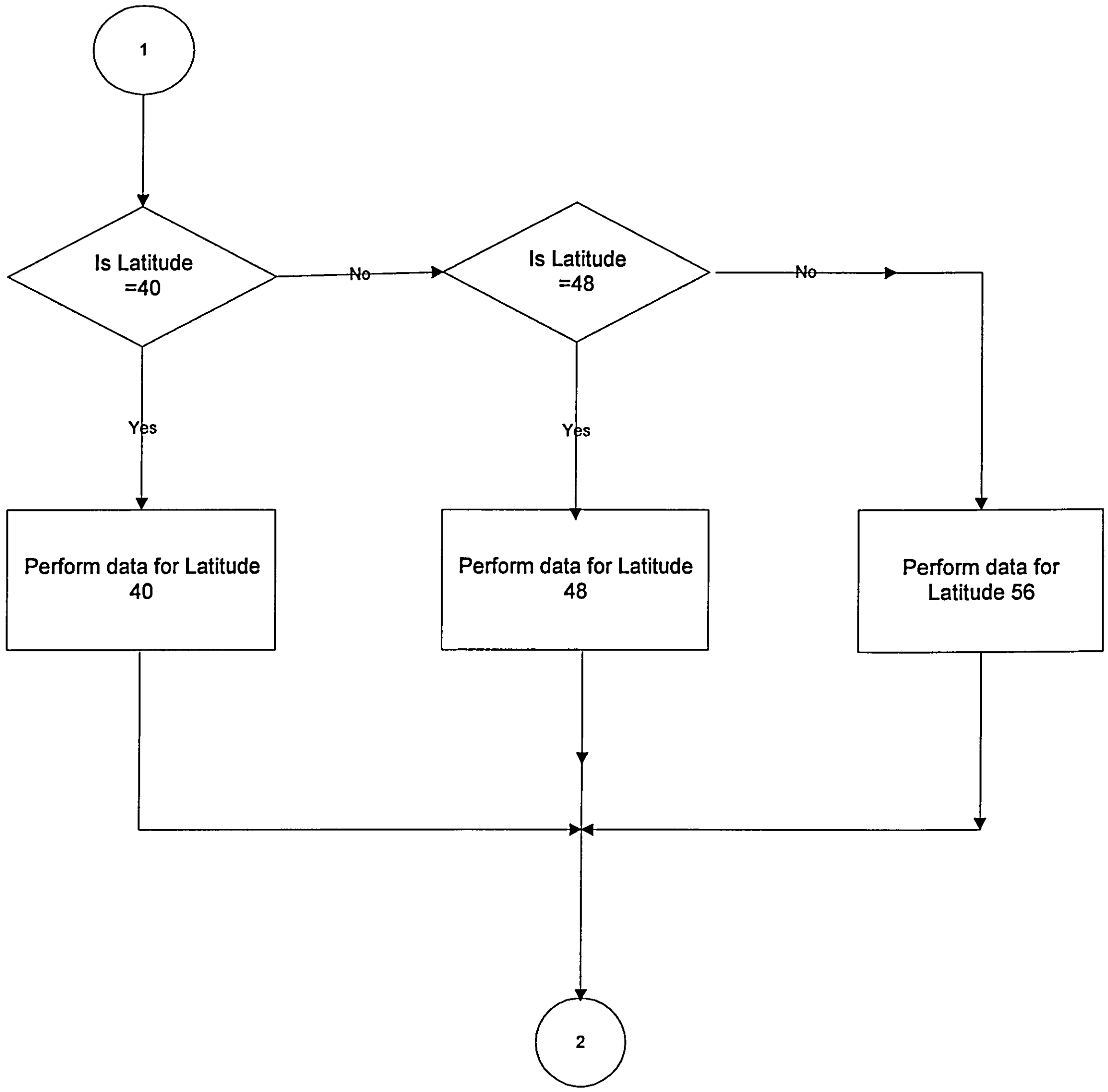
Total cooling load = The sum of each of the component for the above cooling loads

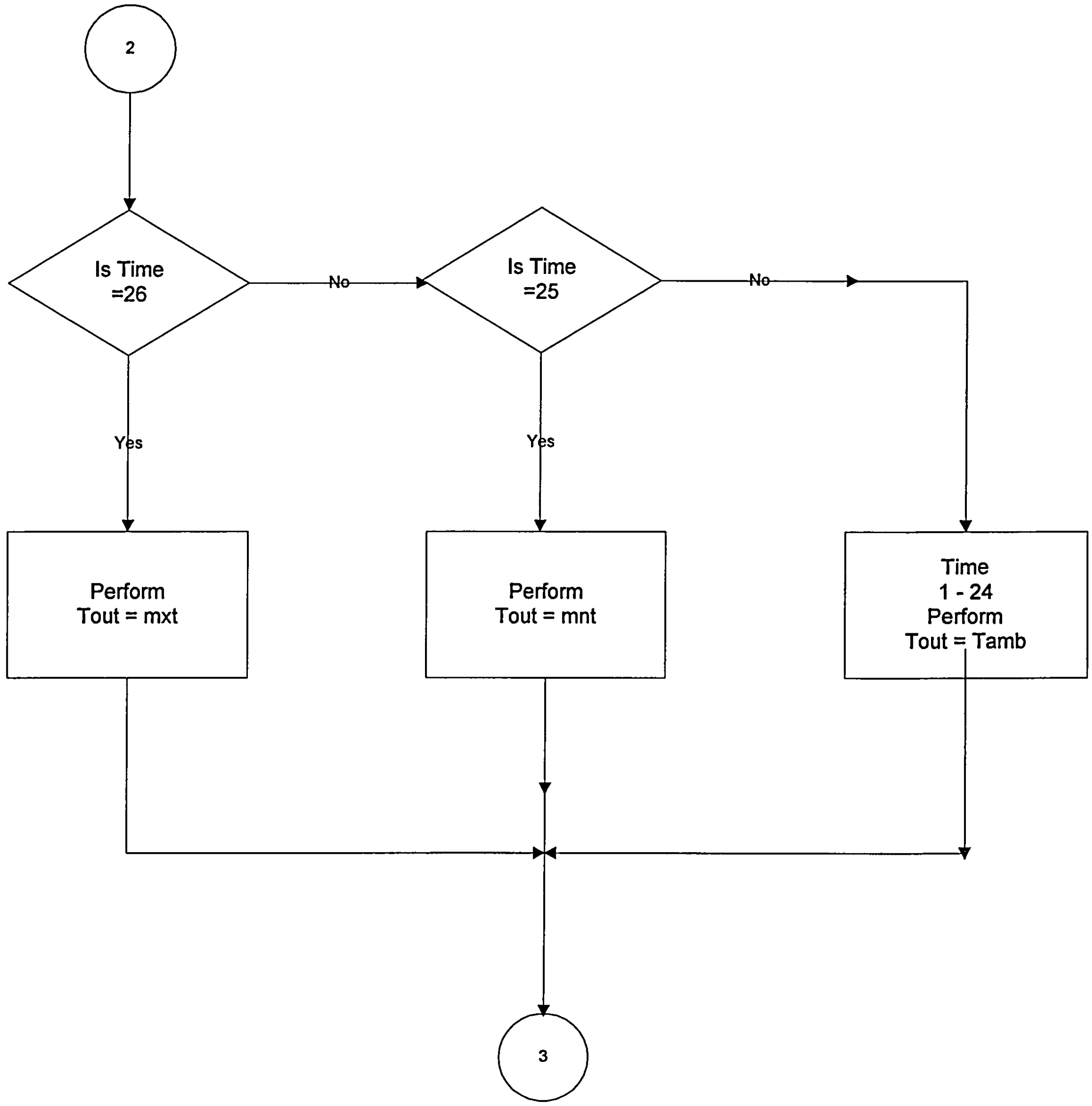
The output for the program is the daily cooling load for the particular input hour.

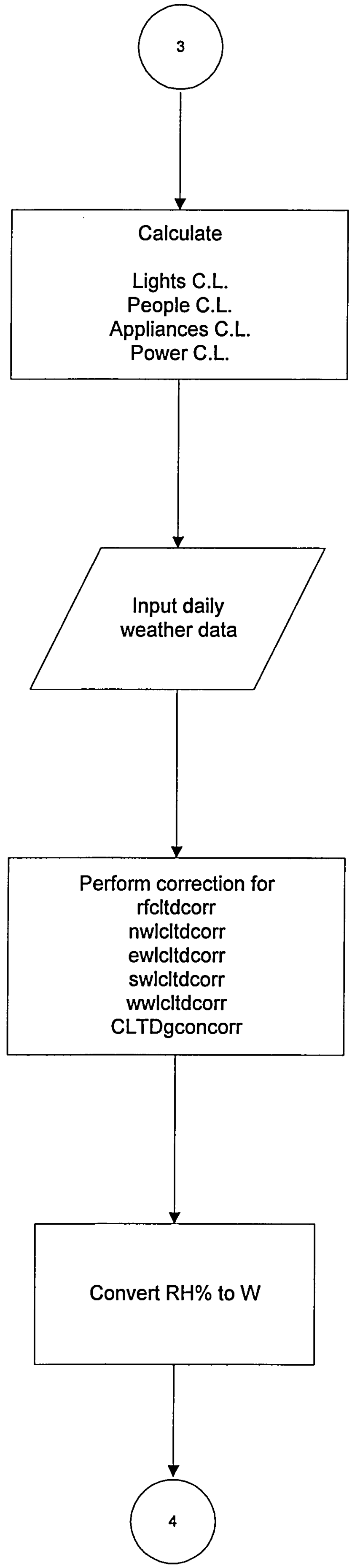
Appendix E

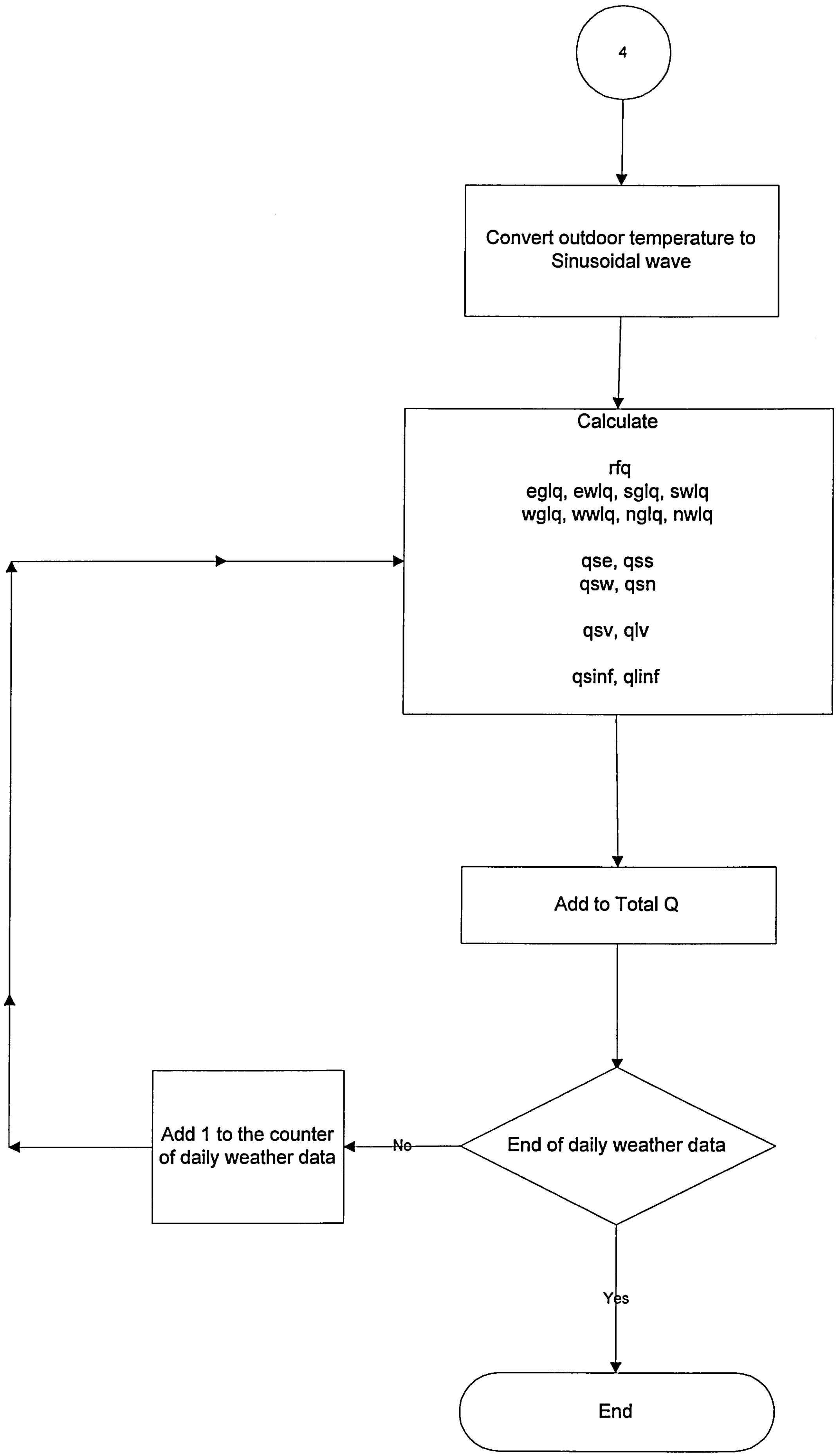
Program Flowchart




1
Is Latitude =40
No
Is Latitude =48
No
Yes
Yes
Perform data for Latitude 40
Perform data for Latitude 48
Perform data for Latitude 56
2


2
Is Time
=26
No
Is Time
=25
No
Yes
Yes
Perform
Tout = mxt
Perform
Tout = mnt
Time
1 - 24
Perform
Tout = Tamb
3


3
Calculate
Lights C.L.
People C.L.
Appliances C.L.
Power C.L.
Input daily weather data
Perform correction for
rfcltdcorr
nwlcltdcorr
ewlcltdcorr
swlcltdcorr
wwlcltdcorr
CLTDgconcorr
Convert RH% to W
4

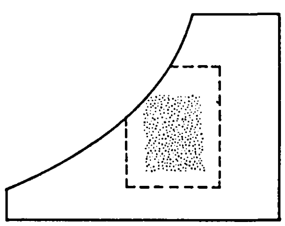

4
Convert outdoor temperature to Sinusoidal wave
Calculate
rfq
eglq, ewlq, sglq, swlq
wglq, wwlq, nglq, nwlq
qse, qss
qsw, qsn
qsv, qlv
qsinf, qlinf
Add to Total Q
End of daily weather data
No
Add 1 to the counter of daily weather data
Yes
End

Appendix F

COOLING LOAD REDUCTION

A.F.1 Introduction

The comfort zone presented in figure A.F.1 indicates conditions in which most people feel comfortable in the shade. When conditions of temperature and relative humidity fall outside the comfort zone, corrective measures such as the addition of air motion, radiant heat, cooling, humidification, dehumidification can produce comfortable conditions. In many cases, these may be achieved by natural means (landscaping, openings in the structure, building form, insulation, and other design arrangements), whereas mechanical air conditioning is more practical in others.



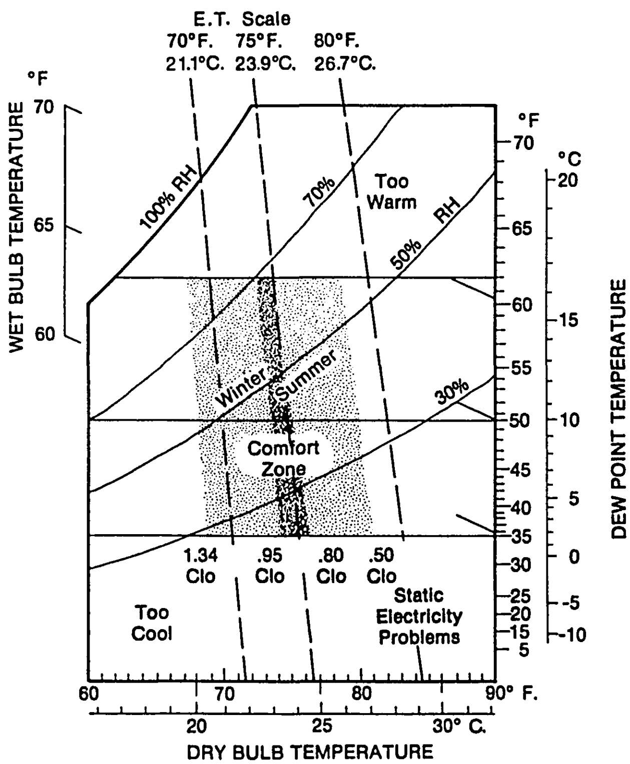


FIGURE A.F.1 The comfort chart

Active HVAC systems are intended to overcome the natural tendencies of heat flow. Passive systems, as an alternative, work with nature instead of against it.

Generally they are low technology, and lower in cost, and should be designed to be aesthetically appropriate.

If the passive systems have load reduction on the active HVAC systems while still providing the necessary comfort conditions, a number of savings may be realised. If the peak heating or cooling loads are reduced, the HVAC equipment and distribution systems may be smaller and less costly.

Generally, that will also result in lower annual energy usage, and thus lower heating and cooling costs. Since the systems and equipment would be smaller, they would consume less space within the building.

The most simple and inexpensive ways to provide comfort, and the ones to consider first, are those that reduce the heating and cooling loads. Next we have consider the ways of satisfying a portion or all of the reduced loads by passive solar heating or passive cooling methods. Only then after the loads have been reduced or satisfied by passive methods as far as economically feasible, should active HVAC systems be designed. In some cases, it may be possible to dispense with a heating or cooling system entirely, or else the loads may be substantially reduced before the final selection and sizing of equipment.

Many passive methods relate to the building envelope [27]. These are concerned with wall and roof insulation, fenestration areas, and types of glazing. Natural conditions such as sun, wind, and vegetation should be regarded as resources to be manipulated with the aid of passive techniques rather than as intruders.

A.F.2 Site Planning

Co-operating with the site requires an overall strategy taking into account existing site conditions, climatic conditions, and the intended use of the building. An internal-load-dominated building requires a program for reducing heat gain and dissipating its surplus. Depending on the balance between the internal gains and the rate of winter heat loss through the skin, these buildings may be in a cooling mode during all or a large portion of the year. If passive cooling through the envelope is planned for these types of buildings, heat flow must be facilitated from the interior core, where the heat is generated, to the skin, where it can be dissipated; or else an imbalance may exist where it is so hot in the interior that mechanical cooling is needed and so cold at the perimeter that mechanical heating is needed.

Buildings without a high density of internal gains (such as residences and light commercial buildings), or assembly halls used only intermittently (such as places of worship occupied only a few times a week) are much more sensitive to climate. The annual temperature extremes and their duration dictate whether the building must be designed for heat retention and passive solar heating in the winter, heat dissipation in the summer, or both.

A.F.3 Climate

The principle climatic variables are temperature range and extremes on an annual and daily basis, humidity, solar radiation, winds, and precipitation. The microclimate at a particular site can be substantially different from the general regional climate. The basic determinants are the earth's heat-storage capacity, the atmosphere, and winds.

Wind currents blow warm or cold air from other regions. During the day light hours, the sunshine has a warming influence on the air and the ground. But the large heat-storage capacity prevents the earth from heating up too much during the day or cooling off too greatly at night. In addition, since moisture can hold a large amount of latent heat, humidity levels in the air are a major determinant of the magnitude of air temperature swings.

The layer of atmosphere around the earth acts as a blanket to keep heat from escaping from the earth too rapidly. It selectively passes solar radiation emanating from a source at more than 5,000°F (2760°C), but retards the passage of radiation from lower-temperature terrestrial sources. This is referred to as the greenhouse effect. Radiant heat escapes through our atmosphere much more quickly during a clear night sky. A cloud cover not only keeps sunshine out during the day, but also keeps radiant heat in at night.

Even though there is a symmetrical pattern of solar radiation around noon, afternoon temperatures are warmer than those in the morning because the earth's storage capacity creates a thermal lag. Likewise, the lowest daily temperature is usually just before sunrise because it takes that long for the previous day's heat to be drained away. As soon as the sun comes up, it begins to heat up the environment.

Because of the long-term effect of the thermal storage, summer temperatures typically reach their peak in July or August, even though the peak solar radiation occurs in June. The earth and its water bodies don't heat up to their maximum temperatures until about a month after the maximum solar input. It takes until January or February a month or two past the winter solstice to reach the coldest winter temperatures because the ground must first deplete its thermal storage.

Geographically speaking, climates are usually colder at higher latitudes (both north and south), since the days are shorter and there is less solar radiation. Microclimatic effects such as elevation, proximity to large water bodies, shading, and wind patterns can, however, alter this trend.

While climates can be described in numerous ways, they are usually classified into four climatic types for which specific design responses have been established. These are:

Cold. Characterised by long, cold winters and short, very hot periods occasionally during the summer. Generally occurring above 45° latitude. The design responses emphasise heat retention, wind protection, passive solar utilisation, and provisions for rain and snow.

Temperate. Characterised by cold winters, which require considerations for heating, and hot summers, which require some cooling efforts, especially if the summers are humid. Generally within a band between 35-45° latitude.

Hot arid. Characterised by long hot summers, short sunny winters, and a wide daily temperature range between dawn and the warmest part of the afternoon. Concerns are with heat and sun control, wind utilisation, rain utilisation, and increasing humidity. For example in the United states, generally the southwest portion.

Hot humid. Characterised by very long summers, only slight seasonal variation, and relatively constant temperatures. Heat and humidity are the chief comfort concerns. Solar shading, heat-gain reduction, and wind utilisation are the focus of load reduction. Occurs in the southeast portion of the United States.

A.F.4 Siting

An analysis of the heating and cooling requirements, the regional climate, and the local microclimate will determine if sunshine, shading, winds, or evaporative cooling is needed. The site should be studied to determine which are the prevailing seasonal winds so that the building can be placed to either take advantage of them or be sheltered from them. The topography, if anything other than flat, can influence the relative windiness of different locations on the site. Existing vegetation may be another determinant in building location on the site. Minor landscaping can augment the existing trees and shrubs. A careful analysis of shading and wind sheltering by both existing trees and proposed plantings at various times of the year is warranted.

Cold Climates. The most important considerations in placing climate-sensitive buildings on a site in a cold climate are access to winter sun and shelter from winter winds. Exposure to morning is O.K. for most of the year, but shade should be provided to the west and northwest in the summer.

Areas to be avoided include valley bottoms where cold air collects, north slopes with reduced sun exposure and greater exposure to cold winter winds, and hilltops where cold winter winds that carry off heat are the strongest.

These buildings should ideally be placed on south-facing slopes. The buildings can even be set into the slope or buried entirely underground for greater isolation from the climate. In some cases, sites below hilltops are subject to cool air currents naturally flowing downhill.

Temperate Climate. Climate sensitive-buildings here should be accessible to winter sun and summer breezes, yet be sheltered from winter storm winds. Summer shading is important to the east, west, and over the roof.

Hot Arid Climate. Summer shading is most important here, especially to the west and over the roof. Some access to winter sun and sheltering from winds are desirable. Building sites in valleys near a water course can keep structures quite a bit cooler than poorly ventilated locations.

Hot Humid Climates. Building in this type of climate should have their wall openings away from major noise sources so that the building can be opened up for natural ventilation. Ideally, floors should be raised up above the ground with crawl spaces underneath for good air circulation. Shading and access to breezes are important. Some access to winter sun may be desirable.

A.F.5 Solar Controls

Solar radiation potentially contributes heat, light, and glare to a site. The shadows cast by land forms, other structures, or vegetation should be analysed for the critical times of year and periods of the day, and the building location selected on the basis of whether winter heating, summer shading, or both are desired.

Glare from nearby water bodies or a sea of parked cars can be controlled by proper siting or a strategic use of bushes, and fences without obstructing desired solar heat.

To take advantage of the sun in the winter, the location selected on the site must be free of obstruction to winter sunshine, or must receive the most sun during the hours of maximum solar radiation. Buildings blocked from exposure to the low winter sun between the hours of 9:00 a.m. and 3:00 p.m. cannot make direct use of the sun's energy for heating. During the winter months, approximately 90% of the sun's energy output occurs between those hours, so any surrounding objects, such as buildings or tall trees, that block the sun during that period will severely limit the use of solar energy as a heating sources. Placing a building in the northern portion of a sunny area minimises the possibility of shading by off-site developments in the future.

Summer shading of windows, walls and roofs can be achieved by other structures (new or existing), shading elements that are part of the building, or surrounding vegetation (Figure A.F.2). Shading devices such as roof overhangs, screens, and fins can be designed to allow winter sun to penetrate to buildings that need heating.

Other buildings can be useful in providing shade on a proposed structure, but such shade from off-site buildings cannot be entirely relied upon unless there is some certainty that they will remain in their existing condition. While other provisions can be retrofitted later in the event that a neighbouring building is demolished, it is a good idea to formulate such back-up plans in advance.

Back-up plans should similarly be prepared for shading effects of trees since they can die or be removed for other reasons. It may take many years for replacement trees to achieve an equal shading effectiveness.

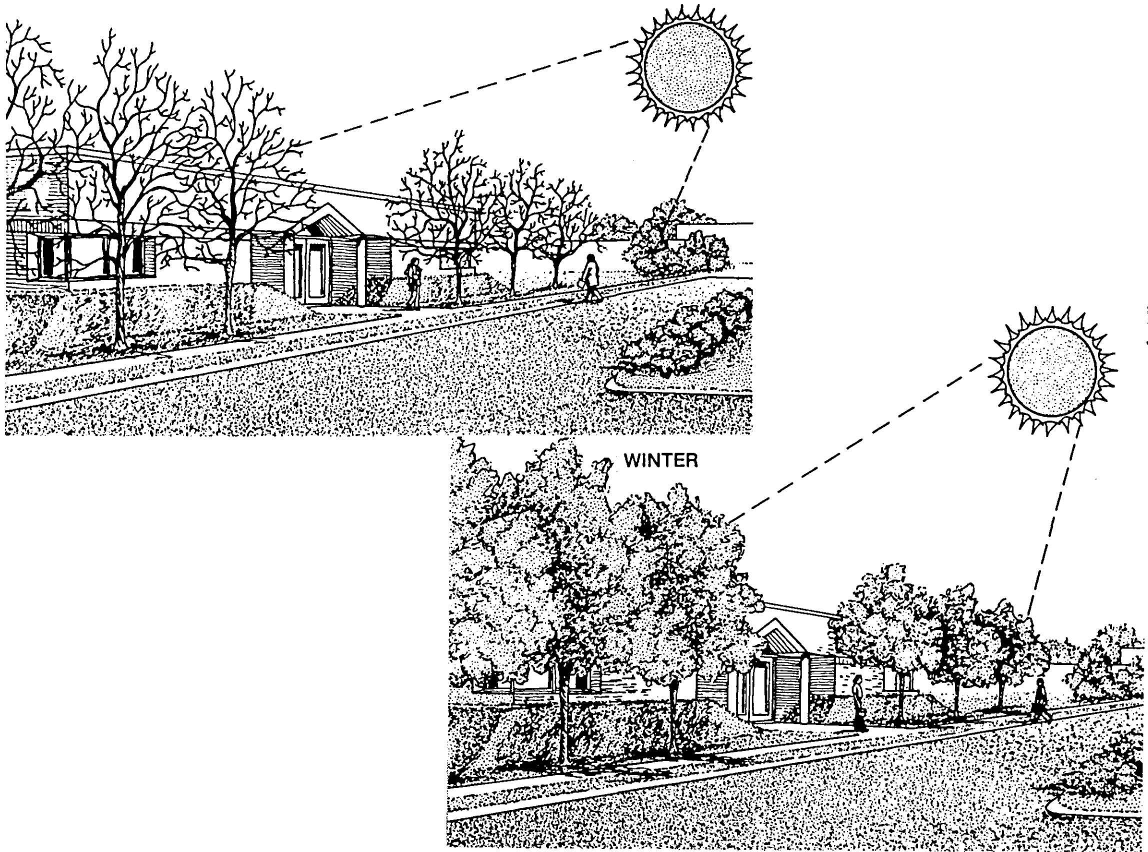


FIGURE A.F.2 Shading by deciduous vegetation

Besides the uncertainty of trees being removed, they can also grow beyond their present proportions. Remember to anticipate where existing trees eventually be, or else plan for periodic pruning and trimming.

A.F.6 Vegetation

Vegetation has many aesthetic advantages on a site in addition to its practical shading function. Other related benefits are decreased air pollution, noise, and glare. In order to permit access to summer breezes, aid drainage, and reduce problems from pests, forests or extensive vegetation should be discouraged near a building.

Fixed structures provide shade only as a function of the sun's position. Trees are most effective in front of low-rise buildings at times of day when the sun is low. This makes them useful for intercepting early morning and late afternoon sun on the east-southeast and west-southwest sides of buildings in northern latitudes, or winter sunshine to the south of buildings that are in a cooling mode all year long. At higher sun angles and for taller buildings structure features such as louvers, screens, or overhangs are needed for shade.

The objective of shading is to minimise heat gain during the cooling season of any particular building. The air temperature in the shade of a tree may be 5 to 10 °F (3 to 6°C) cooler than the surrounding ambient air temperature.

The effect on shaded walls is even more dramatic. Studies have shown that when shaded by a single large tree in direct sunlight, a wall may experience a drop in temperature of 20 to 25°F (11 to 14°C). Even when there is no direct sunlight on the walls, shading by a large tree can reduce the walls temperature by 5 to 10°F (3 to 6°C).

Wall temperatures are also significantly lowered by shrubs located immediately adjacent to the wall. Measurements have shown wall temperature reductions of 20 to 25°F (11 to 14°C) during periods of direct sunlight and 5 to 10°F (3 to 6° C) during periods of indirect sunlight for a moderate-size shrub (5 feet tall and 4 feet wide). The effect is compounded when a wall shielded by a hedge is also shaded by a tree. A wall temperature reduction of 10° F (6°C) has been found during periods of indirect sunshine, while temperature reductions approaching 30°F (17°C) have been observed when the wall is in direct sunlight.

These marked reductions in heat gain occur not only because vegetation shades the wall surface from the sun's rays, but also because the enormous surface area of the leaves are engaged in evapotranspiration, which actually evaporatively cools the air. The shrubs adjacent to the wall also trap the cooled air, creating a blanket of cool stagnant air next to the building surface.

Another factor reducing loads is decreased air infiltration.

Shading west-southwest walls and the roof reduces envelope loads not only at the typical peak-load time of a building, but also at the time of day (late afternoon) that is usually the peak period of the electrical utility. If air-conditioning consumption can be decreased during the peak-load period, less utility capacity will be needed. Such reduction in both building peak load and utility peak load result in a positive environmental impact beyond the boundaries site. If a number of customers of the same utility all reduce their demand for cooling during the utility's peak period, it is possible that less electricity-generating capacity will need to be built.

In addition to shading, which reduces cooling needs in specific areas or for specific structures, trees also cool whole neighbourhoods by lowering air temperatures. During the day, for instance, the air temperature in a forest may be 25°F(14°C) cooler than the temperature at the top of the tree canopy.

Similarly, neighbourhoods with large trees may have maximum air temperatures up to 10°F (6°C) lower than similar neighbourhoods without trees.

All sunlight is converted to heat, whether the sunlight is direct or reflected, and whether it strikes the outer surfaces of a building directly or streams through windows onto the floors or walls. Light striking nearby ground surfaces and objects heats these materials, which also warms the air immediately surrounding the building. As part of the overall landscape planning of a site, a lawn or other low ground cover, due to its evapotranspiration, can cool an area by as much as 1,500 Btuh/ft^2 (4,750 W/m^2) during the summer. This can make a moist lawn 10 to 15°F (6 to 8°C) cooler than bare soil and 30°F (17°C) cooler than unshaded asphalt, even though it does not provide any shade to the building. Table A.F.1 lists the relative cooling effect of various ground surfaces.

Excess glare from nearby unshaded ground, water bodies, or car windshields can also be minimised by the use of ground cover such as grass or ivy, which absorbs a fair amount of light. Considering total energy use, lawn areas are relatively energy-intensive because of the gasoline consumed in lawn mowing. However, trees and shrubs may consume even more indirect fossil fuels per unit area because of pesticide and fertiliser requirements. Ideally, low-maintenance native or naturalised species should be utilised near a building on all ground areas that do not already contain trees and shrubs.

Table A.F.1 Outdoor surface temperature

Air temperature (29°C)	Surface temperature(°C)	Deviation from air (K)
Dark asphalt	51	+22
Light asphalt	44	+15
Concrete	42	+13
Short grass	40	+11
Bare ground	38	+9
Tall grass	36	+7

Maximum local cooling occurs when grasses or ground covers are allowed to reach their maximum height.

A whole range of low-growing, low-maintenance, hardy ground covers are generally available for various appearances and textures. Porous paving or paving blocks that allow grass to grow up through them can be used to replace asphalt in order to create cool green surfaces that are sturdy enough to withstand vehicular traffic.

In addition to serving as a useful ground cover, vines also have the potential to cover a large portion of a building in a very short period.

Like trees and shrubs, vines growing on walls or trellises immediately adjacent to walls can significantly lower wall temperatures by shading and evapotranspiration. Wall temperature reductions of 5 to 10°F (3 to 6°C) have been measured for moderately spars vine in indirect light. When the direct solar radiation was at a maximum, the temperature of a vine-covered wall measured 10 to 15°F (6 to 8°C) cooler than an unshaded wall. Thicker vines provide larger temperature reductions, up to about 15°F (8°C). Thus vines can be an effective shading device, but not as effective as trees and shrubs.

Ponds, lakes, or other water bodies on the site can also cool summer breezes by evaporating water into them. Unshaded bodies of water on the sunny side of a building reflect sunlight and solar heat toward it. Thoughtful siting and use of strategic shading devices can block unwanted heat or glare. When locating a building in relation to large water bodies, it is best to build on high ground for both proper drainage and protection against flooding.

A.F.7 Outdoor Spaces

Outdoor spaces such as a plaza next to a building in a cold or temperate climate should be on a sunny side of the building. If placed on the north side, it will be in continual shade for most of the winter and will be wasted because people will not use it. By siting a building into a south- facing slope or by berming earth against the north wall, the shadow cast by the building will be reduced or eliminated. Besides allowing sunlight to reach the north side, covering a north wall with earth provides the additional benefit of reducing heat loss through the wall in winter and heat gain in summer, since ground temperatures are higher in winter and lower in summer than the outdoor air temperature.

In hot climates, outdoor spaces should be situated on a shaded side or else they, too, will be avoided. They should also be in the path of breezes as much as possible. In general, the suitable orientation of an outdoor space in a temperate or hot climate is dependent on the primary season of intended use.

A.F.8 Wind Control

In contrast to the sun, wind should be utilised during warm periods and blocked during cool periods to aid in the natural conditioning. In designing for wind protection and wind use, directions and velocities of the wind should be known in relation to cool and warm periods of day and year. Of all climatic variables, wind is the most affected by individual site conditions, general climatic data will probably be insufficient.

A.F.9 Sheltering

Knowledge of the local prevailing wind direction and winter storm pattern will indicate where to locate windbreaks in order to block the frigid winds of winter. Like prevailing regional winds, both natural and artificial land forms and structures on or near a site can channel air movements into particular patterns. Site flexibility will sometimes allow a building to avoid the most extreme winds, but there may not be much choice on small sites.

Besides being able to provide shade, trees and shrubs are fairly effective as windbreaks for low-rise building. Evergreen are best suited for this purpose because they maintain their dense growth during the winter. Placing fences, bushes, trees, and other objects in the direction of prevailing winter winds creates an area of relative calm on their leeward side and protects a building from cold winter winds. By providing this buffer, they reduce heat transmission loss and cold air infiltration (Figure A.F.3).

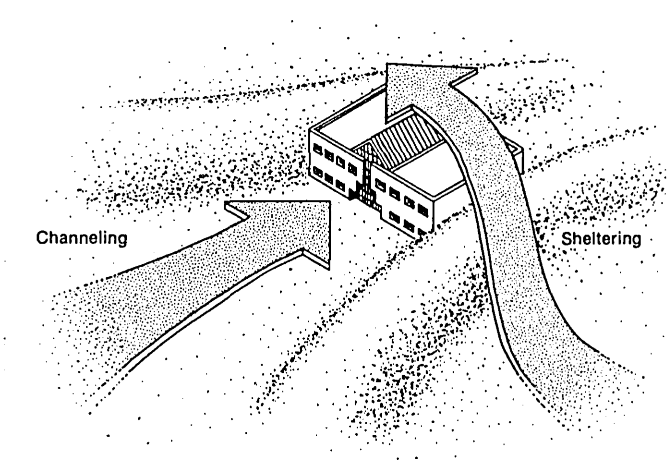


FIGURE A.F.3 Wind breaks and channelling by site resources

Wind directly striking a solid windbreak (a wall, earth berm, or another building) is reduced in velocity from 100% at the break to about 50% at distances equivalent to about 10 to 15 times the height of the break. Open windbreaks, such trees and bushes, offer a maximum reduction in wind speed of about 50% at a distance equivalent to about 5 times the height of the object. But the more open a windbreak, the greater the downwind distance of effectiveness because a larger downbreak (leeward) side wake is formed.

Windbreaks may also be an integral part of a building structure. Such protrusions as parapets or fin walls on the windward side of a building can divert air movement away from other wall and roof surfaces. If retaining winter heat is the objective, utilising hills or below-grade construction can also shield buildings from cold winds. In a desert environment, windbreaks can also act as a desirable buffer to keep hot sandy winds reaching a building.

When providing windbreaks, especially in urban areas, consideration should be given to the impact such redirection of wind will have on the surrounding environment. The concrete canyons of high-rise cities are an example of how funnelling wind currents can produce blustery, eddying wind patterns.

Buildings and their surrounding landscape should be designed so that wind speeds near pedestrian areas and openings do not exceed 10 mph. Large podium bases, wide canopies, and enclosed malls are some of the ways to shield pedestrian areas. In critical cases, scale models of tall building can be studied in wind tunnels to help predict wind speeds.

A.F.10 Channelling Wind

Site development, including landscaping and other structures, can be used to channel cooling breezes in order to carry away unwanted heat and moisture from a building. Wind convicts heat away from roof and wall surfaces and can be funnelled through the building for natural ventilation. Windbreaks adjacent to buildings can change the direction of air flow around and through the buildings while at the same time increasing or decreasing the wind speed.

Ideally, careful placement of windbreaks allows summer breezes in while blocking out cold winter winds. While this is not always possible, in many localities the prevailing winds in summer and winter come from different directions, which simplifies the site strategy.

In areas where prevailing summer and winter winds come from the same direction, deciduous trees and hedges with a low, open branch structure may be used to direct summer winds toward the building. In winter, the bare branches allow cold winds to pass by, undeflected.

In areas where summer and winter winds come from different directions, ventilation openings and windows should be placed in the direction of summer winds. If, however, such a window arrangement conflicts with proper solar protection, summer winds can be directed into the building by additional windbreaks. In some cases, strategic plantings can be placed so as to combine shading and wind-directing benefits for optimum effects. In some cases, however, a compromise is necessary.

In hot humid climates, where maximum ventilation is required, the velocity of the wind, and hence its effectiveness as a cooling agent, can be increased by using windbreaks to constrict and accelerate wind flow in the vicinity of the building.

A.F.11 Building Form, Orientation, and Colour

A.F.11.1 Building Form

A.F.11.1.1 Indigenous Material

Architects and the entire building team should work with local material as much as possible. The least energy-intensive materials are those requiring the least energy for fabrication, transportation, erection, and maintenance.

A.F.11.1.2 Shape

A building may be thought of as forming a footprint on the land. The architecture should strive for a design that is both geographically and culturally appropriate by being within the regional stylistic vernacular. Other factor that influence building shape include the limitations of the site and the needs of the occupants. Beyond the demands of these factors, energy efficiency can be incorporated into the structure.

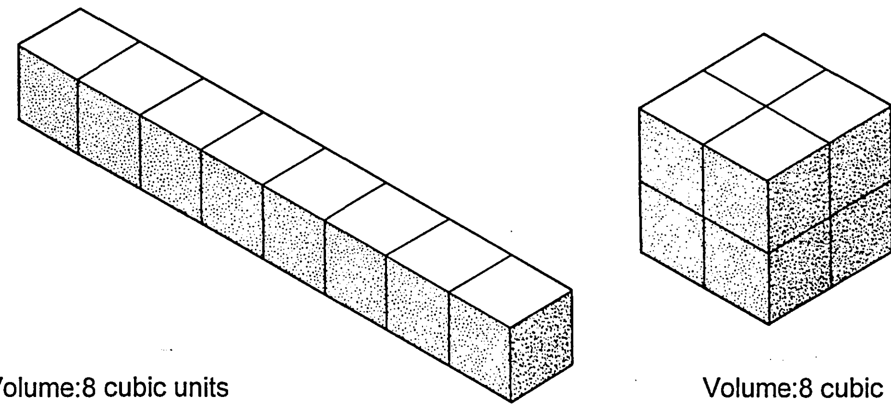
Again, bearing in mind the primary distinction between an internal-load-dominated and a skin-load-dominated building in terms of their need for interaction with the environment. The former needs to dissipate the correct amount of heat throughout the year. The latter needs to a minimum of heat and gain the maximum amount of solar radiation in winter, while gaining a minimum of transmitted heat and solar heat in the summer.

The first basic concept in building shape is the ratio of building length to width to height. The ratio of length to width is given the name aspect ratio. The height is usually expressed in terms of the number of stories for a given floor area requirement.

Victor Olgyay [28], an early pioneer in the subject, has described that the optimum shape for a skin-load-dominated building in any climate is a rectangular form elongated to some degree in the east-west direction.

The longer southern facade of the structure provides a maximum of solar gain in the winter, when the bulk of the sun shine is low in the southern sky. The smaller eastern and western exposures minimise heat gain from the longer, low easterly and westerly sweeps of the sun in summer. The optimum amount of elongation depends on the climate and may be limited by the site.

Heat transfer between the interior and exterior is dependent on the surface area of material separating the inside from the outside. A simple, compact form such as a sphere (dome), cylinder, or other regular polygon exposes less surface area than an elongated or complex form with an equal floor area (Figure A.F.4). A form approaching one of these shapes minimises heat transfer, thus conserving heat in cold weather and keeping heat out in hot weather. Likewise, window areas should be minimised to decrease unwanted heat loss and gain.



Volume:8 cubic units
Surface:34 square units

Volume:8 cubic units
Surface:24 square units

FIGURE A.F.4 Surface/Volume Ratio

In areas where summer comfort is the most important consideration, other shapes may be called for. A thinner, more linear plan may take advantage of natural flowthrough or cross ventilation. The building should be open and airy to facilitate the passage of breezes, and have overhangs and other shading devices to protect it from the sun.

Skin-load-dominated buildings in hot arid climates do well with thick, massive walls, which take advantage of the large daily temperature swings common wherever the air is dry. These walls absorb the solar heat during the day reradiate it during cool nights. Where temperature and wind conditions do not lend themselves to natural ventilation, openings and fenestration should be turned away and shaded from the sun and made to face onto an interior courtyard. The courtyard shades, shelters, and keeps dust out of the interior.

Vegetation planted within the courtyard can cool (by evapotranspiration) the air drawn into the building.

In climates with less severe weather, the designer has more flexibility in choosing building shape without any penalty of excessive heat gain or loss.

Internal-load-dominated buildings in climates where the ambient outside temperature is generally cooler than inside temperatures may be low and spread out and have numerous extensions for a maximum surface/volume ratio. This will dissipate heat more effectively.

Roof areas should in general be minimised by being built up in multiple stories instead of spread out in a single story over a large site. In high-precipitation climates, a steep roof pitch more readily rejects snow and rain, thus avoiding structural and leak problems.

A.F.11.1.3 Clustering

The amount of heat gain from sunlight, like the heat gain and loss due to outside air temperature, is directly dependent on the exposed surface area of the building. Clustering attached buildings (Figure A.F.5) both horizontally and vertically reduces the total exposed surface areas of walls and roof. Rows of skin-load-dominated buildings are most energy efficient when they share east and west walls, so that only the end units are exposed on the east or west face.

Minimum surface structures include buried, semi-buried, or excavated buildings. These are only feasible, however, in reasonably dry soils. Internal-load-dominated buildings located in cold climates where outside temperatures are below comfort levels most of the year benefit from exposed surface areas because these facilitate the dissipation of internally generated heat.

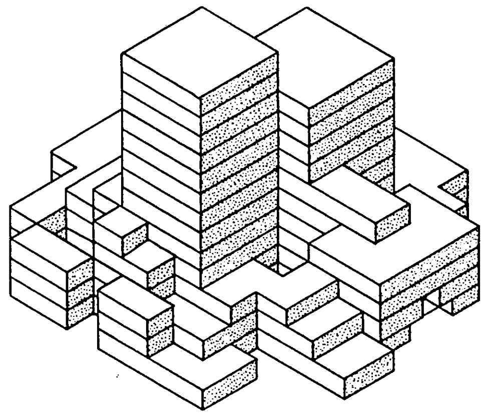


FIGURE A.F.5 Clustering to reduce exposed surface area

The optimum amount of surface area may be calculated by determining the heat loss needed to offset the internal gain when the outdoor temperature is at its annual average. In hot climates, even internal-load-dominated buildings should have a minimum exposed surface area so as not to aggravate the cooling problem.

A.F.11.2 Orientation

Orientation of a building may be affected by function, site or view. Energy requirements are affected by the solar and wind orientation of windows and other openings in the envelope as well as the dominant wall areas.

A.F.11.2.1 Solar

Solar radiation strikes each surface orientation with a different intensity. At latitudes greater than 40 degree north, south walls receive nearly twice as much solar radiation in the winter as in summer. East west sides receive 2.5 times more in summer than they do in winter. At latitudes below 35 degree north, solar gain is even greater on the south side in the winter than in the summer. Table A.F.2 shows how solar radiation varies on the different exposures with different latitudes during different seasons.

We could notice from the table that a building with its long axis oriented east and west has a greater potential for winter solar heat than if it were oriented north-south. Windows oriented to the south provide the highest solar gain in winter but a lower solar gain in summer.

Orienting the shorter side of the building toward the east and west provides high solar gain in summer and low solar gain in winter and also minimises summer cooling loads. This is especially important since the critical period for solar heat gain is usually in the late afternoon, when the sun is low in the west. For that reason, shading the west walls is very important. In lower latitudes, the east walls should be shaded as well.

TABLE A.F.2 Variations in solar intensity on different orientations

LATITUDE	**SEASON**	**SOLAR HEAT GAIN RELATIONSHIPS**
Above 40°N	Winter	South more than 3 times the east and west
	Summer	East and west about 1.3 times the south
35-40°N	Winter	South about 3 times the east and west
	Summer	East and west about 1.5 times the south
Below 35°N	Winter	South about 2 times the east and west
	Summer	East and west 2-3 times the north and south [at lower latitudes, north wall gains surpass south wall gains]

For greatest passive solar heating benefit, the principal facade should face within 30 degree of due south (between south-southeast and south-southwest). Due south is generally preferred, although a slight variation may be beneficial, depending on local conditions at the site.

Since the outdoor air temperatures tend to be lower in the morning than in the afternoon, an orientation slightly east of due south may not only take advantage of the early morning sun, when heat is most needed, but may also allow the building to face away from the west in order to avoid some of the summer afternoon solar heat gain. Where morning sunshine is limited anyway, so an orientation slightly west of due south may be optimum. The optimum orientation varies from site to site and depends on the relative needs for heating and cooling, the time of day when the building is occupied, winds, and other factors.

Internal-load-dominated buildings, which are in a cooling mode all or most of the time, should minimise south, east, and west exposures as well as rooftop areas, which are subject to the highest solar gain [29].

A.F.11.2.2 Wind

Heat losses through building materials and through door and window cracks are directly dependent on exposure to and velocity of wind. Where cold winds are severe, skin-load-dominated buildings should be oriented away from the prevailing storm winds. Walls facing these winds should be windowless and well insulated. Large windows, opening, and outdoor areas should be located on the protected side.

If the size of the site or conflicting concerns do not allow for the proper configuration, or if it is not feasible to orient the building away from winds, the building should be protected by some sort of windbreak on the site. Orientation with respect to prevailing winds is especially important for the tall buildings, many of which cannot be sheltered by trees and other structures. Devices can also be designed that offer solar shading when open and wind protection when closed.

A.F.11.2.3 Self-Shading

Because windows are usually the predominant path of entry for solar energy, economics dictates that efforts at sun control be concentrated on them. In hot climates, all fenestration exposed to direct sunshine should be shaded. Summer shading is vital if glazed areas are used for passive solar heating in the winter.

Shading may also be used over exterior walls and roofs to reduce the amount of solar heat they absorb, and to provide cooler outdoor spaces. Exterior shading may be created by vegetation and other resources on the site, or it may be designed as a building element. The latter includes overhangs, vertical fins, louvers screen panels, egg crate devices, and double roofs. Overhangs can serve other functions such as porches, balconies, verandas, and cantilevered upper floors.

Horizontal overhangs are particularly effective on southern exposures. They can be designed to provide shade in the summer while allowing the low-angle rays of the winter sun to shine through.

Because low early morning and late afternoon sun angles make it necessary that overhangs on east and west walls be excessively wide to be effective, vertical fin construction or some form of screening is best on those exposures. Since the west wall is exposed to direct sun-shine in the late afternoon when most buildings experience their peak cooling load, some form of shading there is very important (Figure A.F.6).

Another type of shading device that can be used as a building component is live vines. Not only are vines able to shade out the sun, but they also provide some insulating capability and cool the air by evapotranspiration. In contrast to shades, which have a darkening effect, vine-covered windows have an airy quality of light and a pleasant atmosphere created by their greenery. This form of shading may reduce solar gain by 20 to 80 %.

One method for supporting twining vines is to install a string, wire, or lath gridwork in front of the surface or area to be shaded or screened from view. Wire mesh, plastic netting, chain link fence, and fish nets are also suitable on which vines will twine and climb.

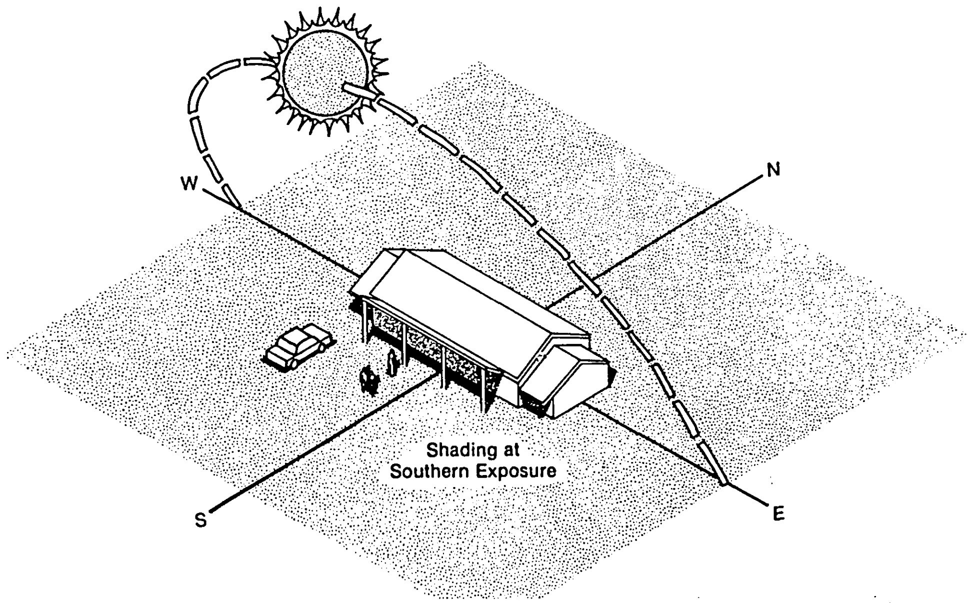


FIGURE A.F.6 Overhangs are of most benefit on the south side (in the northern hemisphere).

For large surface areas, thin wire cable is appropriate. Turnbuckles can be installed and periodically tightened to keep the gridwork taut. Horizontal trellises and arbors can be constructed of a simple latticework of lathing lumber treated with a nontoxic preservative; larger versions can be made of heavy timbers. Detailed and elaborate designs can incorporate fancy millwork, columns, and arches for specific effects.

A.F.11.3 Colour (Surface Reflectivity)

The exterior colour of walls and roofs strongly affects the amount of heat that penetrates into the interior. The more sunlight reflected off the building surfaces, the less absorbed into building materials. Since dark colours absorb much more sunlight than light colours do, white or metallic surfaces should be used in hot climates. Even in temperate areas, light colours should be used for protection during warm spells.

Colour is particularly important when little or no insulation is used. It has less of an effect as the level of insulation is increased.

The ideal dynamic envelope of a skin-load-dominated building would be black in the winter and white in the summer. Since no such surface yet exists, the exterior surfaces on which the summer sun shines in warm climates should be light in colour. In cold climates, dark surfaces on the south face can increase the absorption of solar heat.

Roof colour is important in conjunction with pitch, climate, and the level of internal heat gain. If the need for heating is greater than the need for cooling, dark-coloured, steeply sloped rooftops may absorb solar radiation and transmit some of it into the building.

If the roof is not sloped, the major heat gain will occur in the summer when the sun is high in the sky, and very little heat gain will occur in the winter when the sun is low on horizon. Light-coloured rooftops in those cases will reflect sunlight away from the building and reduce its cooling load.

When both heating and cooling are important, heavy snow conditions may negate the effect of dark surfaces anyway, so light-coloured surfaces provide the best overall benefit. White gravel ballast or light-coloured membranes, shingles, and other surfaces materials can suffice.

A.F.12 Interior Layout

While the building location on the site is being established, the rough shape defined, and shading and orientation selected, the interior spaces should be laid out at the same time for overall compatibility.

Spaces with the maximum heating and lighting requirements should be located along the south face of the building, while buffer areas (toilet rooms, kitchens, corridors, stairwells, storage, garage, and mechanical and utility spaces), which need less light and air conditioning, can be placed along the north or west wall.

Rooms for occupations that require the greatest illumination levels, such as typing, accounting, reading, and draughting, should be located next to the windows and natural lighting, while rooms needing few or no windows for light or view, such as conference rooms, can be located away from window areas. High internal-gain spaces requiring extensive cooling should be located on north and east exposures.

In rooms with large windows, the windows should open to the south if winter heating is needed; summer sun penetration can be controlled by overhangs or other shading devices. In climates where heat loss is not critical in the winter, windows can open both to the north and south. Windows in internal-load-dominated spaces should open to the north or east. In any case, windows on the western side, which are so troublesome for summer cooling, should be kept as small as possible.

Spaces that use passive solar heat or daylight should have a depth in from the south wall no greater than 2.5 times the window height(from the floor to the top of the windows). In most cases, this amounts to a limitation of 15 to 20 feet. This ensures that the direct rays of the sun will penetrate the entire spaces. The limit is about the same even when the heating comes from an opaque radiant thermal storage wall, since this limit is considered the maximum distance for effective radiant heating from a solar wall. Spaces that need to be deeper or in which large south-facing widows are undesirable can let sunlight in through south-facing clerestory windows or skylights.

Note, however, that horizontal skylights gain the most solar heat in the summer, when the sun is directly overhead, and the least during the winter, when the sun angle is too low for solar heat to be effectively transmitted through. Admitting sunlight into a space through the roof has the advantage of allowing flexibility in distributing light and heat to interior parts of a building.

Building entries should be placed so that they are oriented away from and receive the greatest protection from prevailing cold winter winds. Another way to reduce infiltration is to design buffered entries.

Providing an air lock, vestibule, or double entry decreases both the infiltration and conduction transmission through the entry area. Unheated areas such as garages, mud rooms, or sun spaces placed between doors leading to the conditioned spaces and the outside dramatically reduce the air change rate caused by people entering and leaving.

Conventional designs in recent years have made it necessary for fans to operate in order to supply ventilation and some cooling even during periods when outside temperatures do not require heating or cooling. The energy for fans and air conditioning in these cases can be avoided if the interior spaces are laid out in a linear plan to facilitate natural ventilation (Figure A.F.7).

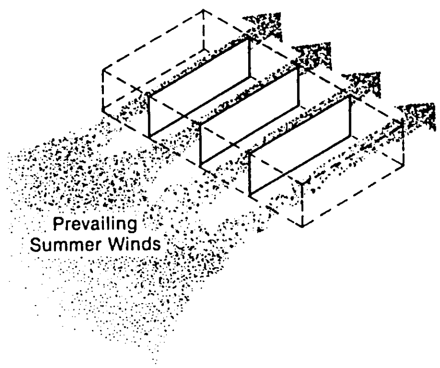
Energy consumption in both constructing and operating building can be minimised by grouping similar functions and needs in proximity to the resources required for those functions at the initial conceptual design stage.

This consolidates and thereby minimises the magnitude and complexity of the distribution networks providing the required mechanical services.

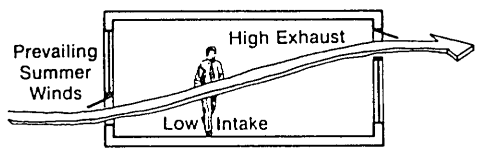
For example, a lecture hall, auditorium, operating room, conference room, or any other room needing both an isolated and closely controlled environment is well suited for an interior or subsurface location.

Areas with the most frequent public activity should be located on or near ground level.

Closed offices or industrial activities with less frequent public contact can be removed to higher levels and more remote locations.



(a)



(b)

FIGURE A.F.7 Interior layout should be conductive to natural ventilation. (a) Partitions should be arranged so as to channel prevailing summer breezes straight through the building. (b) Openings on the leeward side should be higher than openings on the windward side

.

Mechanical spaces should be located with consideration of the needs for acoustic isolation and restricting public access, in conjunction with outside air requirements, access for equipment replacement, and closeness to outside equipment such as condensers or cooling towers.

A.F.13 Creative Solutions

Ideally, a building envelope should moderate temperature extremes both daily and seasonally. On sunny winter days it should be able to be opened up to the sun's heat. At night, it should be able to close out the cold and keep the heat in.

In the summer, it should be able to do just the opposite, close off the sun during the day, and open up at night in order to release heat into the cool night air.

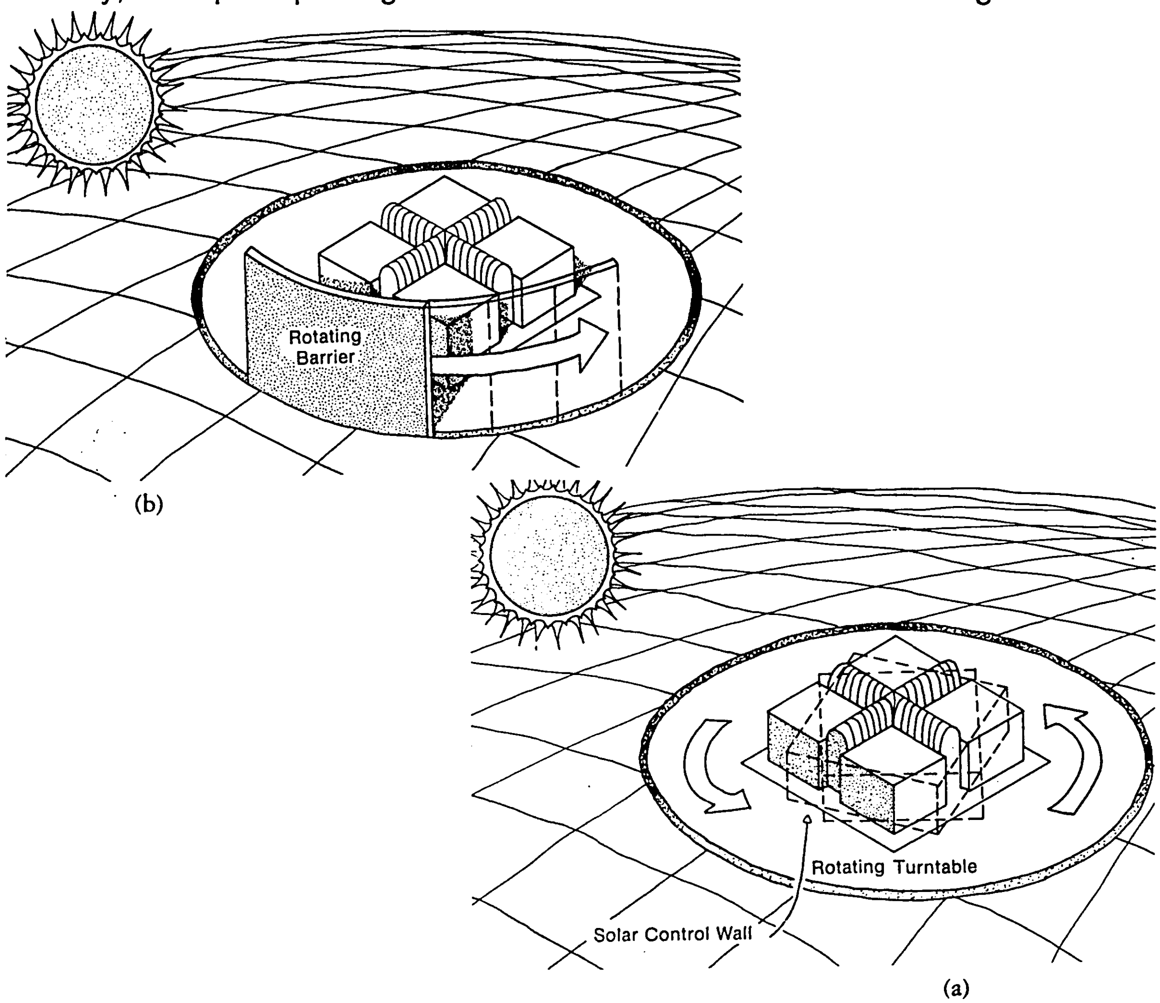


FIGURE A.F.8 Dynamic Envelope (Space-Age Solutions)

A number of imaginative ideas have been suggested to allow a building to respond dynamically to its environment. As illustrated in (Figure A.F.8), the entire structure can be built on a rotating turntable. In this way, the building can have one open exposure directed towards or away from the sun as desired. It can also track the sun as it moves across the sky in its daily cycle.

Another suggestion, also shown in the same figure, is the use of barrier screens that can be moved around a building in response to the movement of the sun. This kind of shading device can also serve as a windbreak.

These ideas are generally impractical because of the tremendous construction cost involved. It is sometimes useful, however, for a designer to let the imagination run wild, and then see how to adapt the results to more practical design solutions.

A.F.14 Insulation and Thermal Mass

The building envelope is a device through which heat exchange between the internal and external environments is controlled. The various modes of operation of an envelope are :

1- Admit heat gain
2- Exclude heat gain
3- Containing internal heat
4- Dissipating excess internal heat

The opaque portions of the envelope, once designed, are generally considered fixed controls. The dynamic elements of the envelope include operable window sashes, window shading devices, and insulating shutters.

The effect of insulation is to reduce heat gain and heat loss. The more insulation in a building's exterior envelope, the less heat transferred into or out of the building due to a temperature difference between the interior and exterior. Insulation also controls the interior mean radiant temperature by isolating the interior surfaces from the influence of the exterior conditions, and also reduces drafts produced by temperature differences between walls and air.

Insulation along with infiltration control is important for reducing heating and cooling loads in skin-load-dominated buildings. Increased insulation levels in internal-load-dominated buildings, however, may cause an increase in energy usage for cooling when the outside air is cooler than the inside, unless natural ventilation or an economiser cycle on the HVAC system is available.

A.F.14.1 Thermal Mass Effect

Conventionally constructed envelopes trend either to have controlled U-values through the use of insulating materials, or to be very dense and heavy in weight.

Massive construction result in thermal time lags (building temperature lags behind the outdoor temperature), which tend to produce more stable interior conditions (Figure A.F.9).

One illustration of the influence of thermal mass is the adobe structures indigenous to the Southwest United States. Due to the low thermal resistance of the masonry-like material, a calculation on the basis of U-value alone would predict that the structure should need a great deal more energy for heating and cooling than is actually the case.

As heat penetrates the wall in the daytime, its heat capacity soaks it up like sponge until the interior surface temperature of the wall rises above the interior air temperature. Only at that time will heat travel to the interior. As a result, there is a time lag between the outside temperature (and solar heat) and the heat gain inside the structure.

Similarly, since the dense, thick wall is holding so much heat at night, it takes a long time to dissipate the heat to the cold outdoors. Thus, as the outside temperature fluctuates, the indoor temperature remains more stable. The greater the mass and thermal capacity, the more stable the indoor temperature.

If the outside temperature fluctuates around a comfortable temperature and the building has enough mass, the structure may not need any active heating or cooling at all. Opening windows at appropriate times in the day/night cycle and collecting solar energy can temper the average temperature.

Massive west wall, east walls, and roofs can greatly minimise solar heat impacts in the summer. Lightweight constructions, by contrast, are more sensitive to short-term temperature and solar impacts. Table A.F.3 gives approximate time lags for various materials.

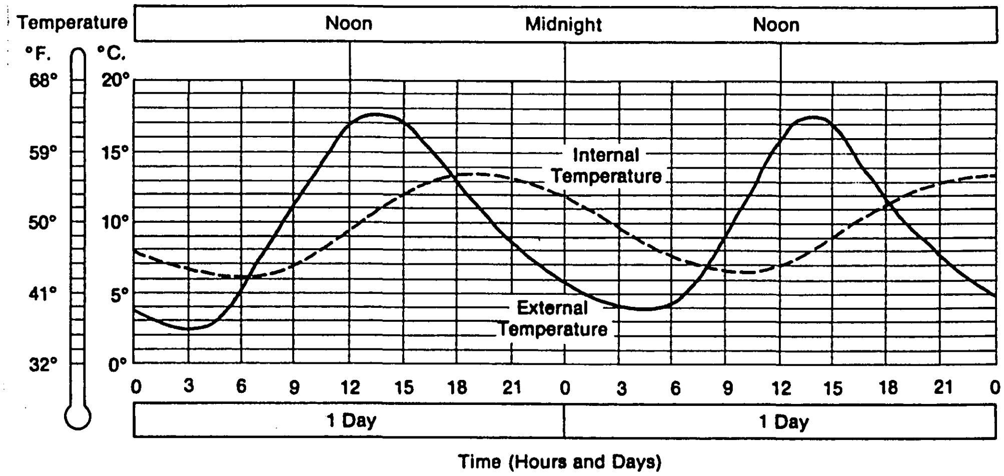


FIGURE A.F.9 Moderating effect of thermal mass, time lag and decreased amplitude

The dynamic thermal performance of a masonry wall is even better when insulation is placed on the exterior side of the wall. Insulated thermal mass is the means of storing heat in passive solar applications. An insulated mass in cold climates can absorb excess internal heat gain and release it to the space during unoccupied periods, thus minimising overall heating requirements.

TABLE A.F.3 Time lag for various materials

MATERIAL	THICKNESS (CM)	TIME LAG
Brick	10	2.5 hr
	20	5.5 hr
	30	8.5 hr
Concrete (sand and gravel aggregate)	10	2.5 hr
	20	5 hr
	30	8 hr
Insulating fibreboard	5	40 min
	10	3 hr
Wood	1	10 min
	2.5	25 min
	5	1 hr

Earth-sheltered buildings employ a special kind of thermal mass. The thermal mass of earth against the exterior walls helps keep the interior at a uniform temperature day and night, throughout the year.

A.F.14.1.1 Thermal Lag Factor

Chapter 2 described how radiant heat gain does not immediately become a load on the cooling system. Instead, it is first absorbed and partially stored when it strikes a solid surface. Only when the solid surfaces become appreciably warmer than the room air does this energy become part of the cooling load.

The lag between the time when the heat enters the space and when it is received by the room air is determined by the heat storage characteristics of the structure and its contents, the presence of shading, and whether the shading is interior or exterior. This delaying of the heat gain can account for a substantial reduction in the peak cooling load.

The magnitude of the storage effect is largely a function of the thermal capacity or heat-holding capacity of the materials surrounding and within the space. The thermal capacity of a material is defined as the weight times the specific heat of the material. Since the specific heat of most construction materials is approximately 0.20 Btu/lb.°F(837 joules/kg.°C), their thermal capacity is directly proportional to their weight.

A.F.14.2 Superinsulation

Superinsulation is the application of greater-than-normal amounts of insulation in order to eliminate all need for mechanical space heating. Internal and solar heat gains became the primary source of heat. The savings on heating equipment and distribution systems may equal or outweigh the additional costs of extra insulation, extra thermal mass, and insulative window treatments.

The crucial concern in superinsulated buildings is preventing overheating both in summer and on moderate days in winter, when solar gains may be especially high.

Designers of internal-load-dominated buildings must be particularly careful not to eliminate the positive aspects of heat dissipation in cool weather. The superinsulation level is generally much lower for these types of buildings.

Since insulation is needed at all exterior surfaces, it can add significantly to construction costs. The desirable amount of insulation must be carefully evaluated. At some point, there is a diminishing return in energy savings on each increment of added insulation. The objective of superinsulation is to justify additional insulation on the bases of reduced mechanical equipment costs. Even so, the point of diminishing returns, at which more insulation ceases to provide sufficient economic benefits, may still be reached.

A.F.15 Fenestration

A building's envelope forms a boundary between the interior environment and the variable external environment. Fenestration refers to glazed openings in the envelope for the purposes of:

1- Illumination
2- View
3- Solar
4- Natural ventilation

Approximately half the energy in the solar radiation that reaches the earth's surface is at wavelengths too long to be visible. While the visible light provides illumination, this infrared radiation is a useful source of heat.

Ordinary clear glass transmits almost all wavelengths of solar radiation except the short ultraviolet component. It thus serves as an effective source of heat and light, as well as providing a feeling of spaciousness and freedom to the occupants.

Despite these potential benefits, fenestration can be an energy liability. Heat transmission through a window can be more than 12 times as much as through a well insulated wall of equal area. Window frames also transmit heat to a varying extent, depending on materials and construction, and pass infiltration through cracks between the sash and the frame. Weather-stripping and gasketing are important components of any operable fenestration.

When the primary objective is minimising heat transmission through the envelope, window areas should be reduced as far as the psychological need for visual contact with the outdoors will allow. But before jumping to that solution, we have to consider the value of passive solar gain, light, and view through the fenestration.

An analysis of the energy impact over an entire yearly cycle of weather is required to ascertain any net energy benefit. Generally, reflective glass has a greater advantage in southern climates than in northern ones.

The different sides of a building need not, and should not be identical in appearance. Each face may need a different response to solar, wind, and view exposure. For example, while reflecting and heat-absorbing glass is rarely needed on north, north-northeast, and north-northwest orientations (except for glare control), they may be useful on the west for limiting summer afternoon heat gain [30],[31].

The factors that affects choosing the right type of glass is transmittance value and reflectance value. Multiple glazing and operable thermal insulation reduce conduction transmission. The shading effectiveness is expressed in terms of shading coefficient (SC), the lower the SC, the less the heat gain. The U-value describes the transmission quality of the device.

Retrofitting existing buildings with suitable solar control devices can achieve substantial reductions in energy consumption.

The most effective way to reduce the solar heat gain through fenestration is to intercept the direct radiation from the sun before it reaches and penetrates the glass. Exterior shading devices dissipate their absorbed heat to the surrounding air, while inside drapes and blinds create a heat trap within the conditioned space. Fully shaded windows achieve a solar heat gain reduction of as much as 80%.

Operable shading such as miniature venetian blinds placed between two layers of glass is not as effective as an exterior device, but is more effective than an interior shading device. Double glazing separated by a (1-cm) air space cuts heat loss through a single-glazed window in half. Two separate windows (such as a single-glazed window with storm window) 2.5 to 10 cm apart, produces the same reduction. Triple glazing generally cuts the heat loss to 2/3 of the loss through a double-pane window.

When the appropriate number of glazing layers is applied for a given climate, the solar gain may turn the window from an energy liability into a source of net energy gain.

A.F.16 Earth Sheltering

The temperature of the earth varies widely from region to region, from season to season, and even over the short distances between neighbouring sites.

Light, dry soil reaches a near constant ground temperature at a shallower depth than heavy, damp soils. The average earth temperature at a given site is generally 2 to 3°F (1 to 1.5°C) above the average annual air temperature, but the earth temperature fluctuates much less than the air temperature. Thus, earth sheltering provides a warmer environment in the winter and a cooler one in the summer.

Earth sheltering can minimise interior temperature swings during all seasons.

But it should be considered within the broader context of the overall control strategy. If an earth- sheltered design compromises the effectiveness of other passive control techniques that are more effective, it is counterproductive.

Earth sheltering is appropriate for all climates except hot humid ones. In those regions the ground tends to be too damp, and the moist summer air condenses on interior walls as it is cooled by the ground. In the south-eastern United States, the most effective passive cooling strategy is natural ventilation. Earth sheltering is beneficial there only when it does not appreciably interfere with ventilation.

By contrast, ventilation is not a desirable passive control strategy in the Southwest States. There, the high mass of the earth can be very beneficial.

Buildings may be completely sunken with a recessed interior courtyard into which cool, dense night air tends to slide. Various passive evaporative cooling techniques may also be used.

Growing plants on earthen roofs and courtyards helps cool by evapotranspiration. In cold climates, earth sheltering can provide protective benefits from exposure to cold winds and the air temperature in general.

Underground construction practically eliminates excess infiltration, but it introduces a need for mechanical ventilation. Energy is conserved, however, since only the air required for adequate ventilation needs to be heated or cooled to room temperature.

Waterproofing, structural design, adequate ventilation are some of the major concerns of underground construction. A rule of thumb is that the air in underground spaces should be kept in motion by natural or mechanical ventilation to avoid condensation.

Concrete walls, if left unsealed, will absorb moisture from the air and drain it away into the earth. where condensation is a potential problem, either the air must be dehumidified or the walls must be warmed.

Interior spaces should be oriented to make maximum use of daylighting, clerestory windows, and internal courtyards. However thermally effective earth sheltering may be, its acceptability depends on the designer's skill in introducing daylight, access, and views.

Under the right conditions, earth sheltering can result in substantial savings on exterior finish materials, as well as reducing transmission and infiltration through walls and openings. Other advantages of earth sheltering are that it is an effective sound insulator, so that the interior spaces are less intruded upon by ambient noise levels, and the construction does not interrupt any pre-existing land use (pedestrian or vehicular traffic, agriculture).

A.F.17 Internal Gain Reduction

Passive load reduction calls for minimising all internal gains. Since the number of people in a building and their activity level are presumably a function of the building program, a portion of the internal gain cannot be reduced. Likewise, all equipment in use is presumed to be essential. Thus, the remaining potential for reducing internal gains lies with turning off unneeded equipment and minimising energy for lighting [32],[33].

Daylighting offers enormous opportunities for reducing cooling loads. The cooling load produced by incandescent lighting is 6 to 10 times greater than that due daylighting for equal lighting levels. If daylighting is not feasible, fluorescent and H.I.D. (high intensity discharge) lighting should be employed for maximum lighting efficiency.

Another area of great potential is the industrial environment. Process heating equipment can be better insulated and/or relocated where it will not contribute as much toward internal loads. Water tanks and drains can be covered. These measures not only reduce the internal heat gain, but may also save process energy.

Exhaust hoods can be used to capture heat rising from hot processes. If there are hot objects such as furnaces, molten material, or hot ingots, the major heat source is in the form of radiant heat. Radiant heat can be reduced by lowering the surface temperatures of the hot objects by insulation, water-cooling, or shielding.

A.F.18 Conclusion

If the passive systems have load reduction on the active HVAC systems while still providing the necessary comfort conditions, a number of savings may be realised. If the peak heating or cooling loads are reduced, the HVAC equipment and distribution systems may be smaller and less costly.

Generally, that will also result in lower annual energy usage, and thus lower heating and cooling costs. Since the systems and equipment would be smaller, they would consume less space within the building.

The most simple and inexpensive ways to provide comfort, and the ones to consider first, are those that reduce the heating and cooling loads. Next we have to consider the ways of satisfying a portion or all of the reduced loads by passive solar heating or passive cooling methods.

Only then after the loads have been reduced or satisfied by passive methods as far as economically feasible, should active HVAC systems be designed. In some cases, it may be possible to dispense with a heating or cooling system entirely, or else the loads may be substantially reduced before the final selection and sizing of equipment [5].

Appendix G

PROGRAM VALIDATION

Maximum and minimum dry bulb temperatures of 29 °C and 20 °C respectively, together with Relative humidity of 65% at 22.1°C have been used for this calculation.

Roof $Q = U \times AREA \times CLTD$
Roof $Q = .510204 \times 4225 \times 16.6$

Roof Q = 35783.157 W

East Wall $Q = U \times AREA \times CLTD$
East Wall $Q = 2.97661904 \times 1240 \times 11.1$

East Wall Q = 40964.283 W

East Glass $Q = U \times AREA \times CLTD$
East Glass $Q = 4.3859649 \times 60 \times 4.6$

East Glass Q = 1210.5263 W

South Wall $Q = U \times AREA \times CLTD$
South Wall $Q = 4.347826 \times 1240 \times 9.8$

South Wall Q = 52834.781 W

South Glass $Q = U \times AREA \times CLTD$
South Glass $Q = 4.\ 3859649 \times 60 \times 4.6$

South Glass Q = 1210.5263 W

West Wall $Q = U \times AREA \times CLTD$
West Wall $Q = 4.347826 \times 1240 \times 12.1$

West Wall Q = 65234.781 W

West Glass $Q = U \times AREA \times CLTD$
West Glass $Q = 4.\ 3859649 \times 60 \times 4.6$

West Glass Q = 1210.5263 W

North Wall $Q = U \times AREA \times CLTD$
North Wall $Q = 4.347826 \times 1240 \times 4.6$

North Wall Q = 24799.999 W

North Glass $Q = U \times AREA \times CLTD$
North Glass $Q = 4.\ 3859649 \times 60 \times 4.6$

North Glass Q = 1210.5263 W

East Glass Solar Q = AREA × Sc ×SHGF × CLF
East Glass Solar Q = 60 × .55 × 675 × .8

East Glass Solar Q = 17820 W

South Glass Solar Q = AREA × Sc ×SHGF × CLF
South Glass Solar Q = 60 × .55 × 461 × .83

South Glass Solar Q = 12626.79 W

West Glass Solar Q = AREA × Sc ×SHGF × CLF
West Glass Solar Q = 60 × .55 × 675 × .81

West Glass Solar Q = 18042.75 W

North Glass Solar Q = AREA × Sc ×SHGF × CLF
North Glass Solar Q = 60 × .55 ×117 × .91

North Glass Solar Q = 3513.51 W

Light Q = Watt × Fsa × usefactor × CLF
Light Q = 90000 × 1.2 × .95 × .91

Light Q = 93366 W

People Sensible Q = No. People × 75 × CLF
People Sensible Q = 1000 × 75 × .94

People Sensible Q = 70500 W

People Latent Q = No. people × 55
People Latent Q = 1000 × 55

People Latent Q = 55000 W

Appliances Sensible Q = Heat Gain × u.f × Fra × CLF ×.66
Appliances Sensible Q = 100000 × .5 × .32 × .95 × .66

Appliances Sensible Q = 10032 W

Appliances Latent Q = Heat Gain × .34
Appliances Latent Q = 100000 × .34

Appliances Latent Q = 34000 W

Power Q = Power Heat Gain/ m.efficiency × Fum × Flm × CLF

Power Q = (10000/(81/100)) × 1 × 1 × .95

Power Q = 11728.395 W

Ventilation Sensible Q = 1.23 × Air required/people × Δt
Ventilation Sensible Q = 1.23 × 7000 × (29-24)

Ventilation Sensible Q = 43050 W

Ventilation Latent Q = 3010 × Air required/people × Δw
Ventilation Latent Q = 3010 × 7000 × (0.010775-0.009317)

Ventilation Latent Q = 30720.06 W

Infiltration Sensible Q = 1.23 × Air required/Crack × Δt
Infiltration Sensible Q = 1.23 × {1.180555 × [2 × (15+4) × 4] }× (29-24)

Infiltration Sensible Q = 1103.5828 W

Infiltration Latent Q = 3010 × Air required/Crack × Δw
Infiltration Latent Q = 3010 × {1.180555 × [2 × (15+4) × 4] }× (0.010775-0.009317)

Infiltration Latent Q = 787.505 W

MANUAL CALCULATION TOTAL COOLING LOAD = 626749.65 W

PROGRAM CALCULATION TOTAL COOLING LOAD = 626749.7 W

Figure A.G.1 Values of each of the Elements that Contributed to the Total Cooling Load

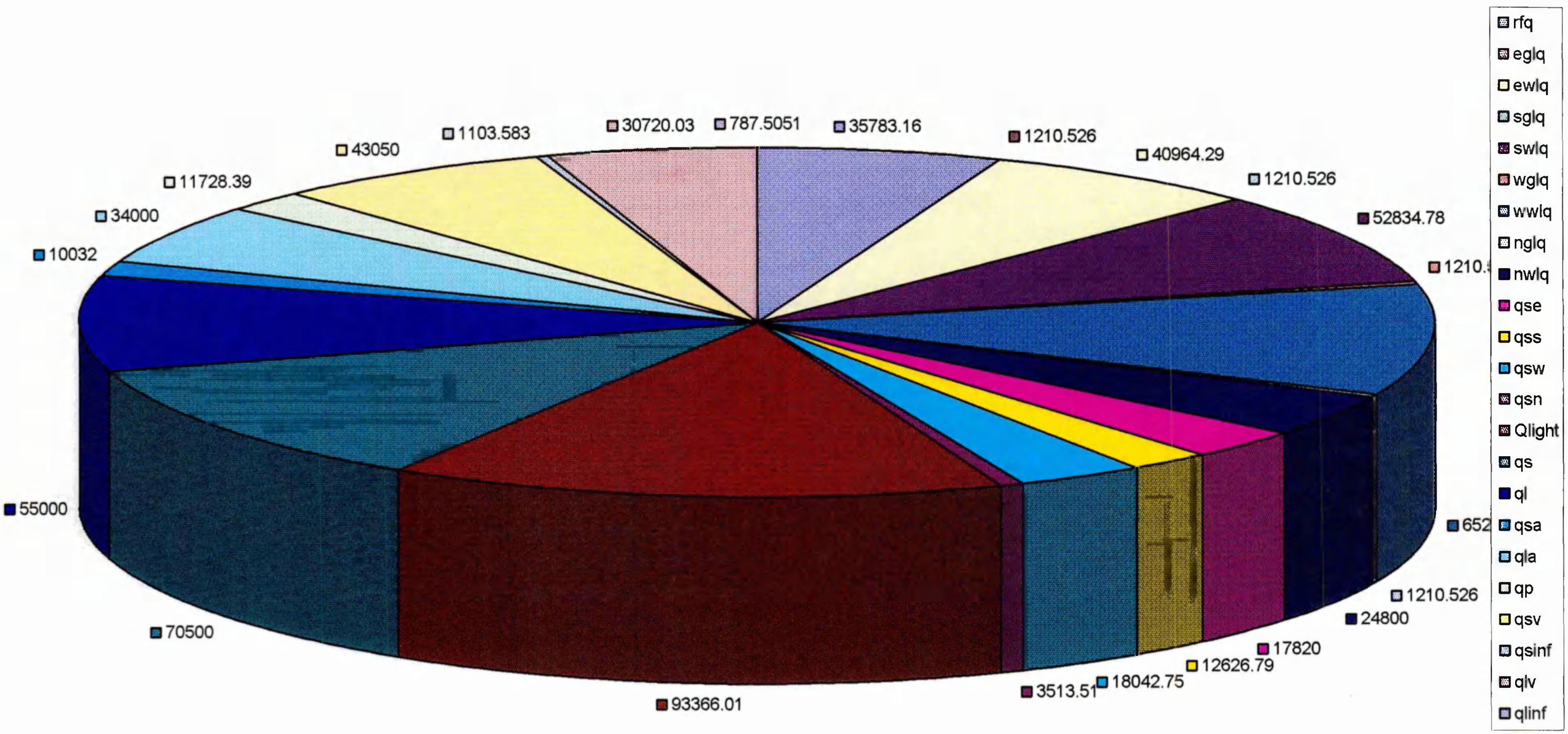


Figure A.G.2 Percentage of each of the Elements that Contributed to the Total Cooling Load