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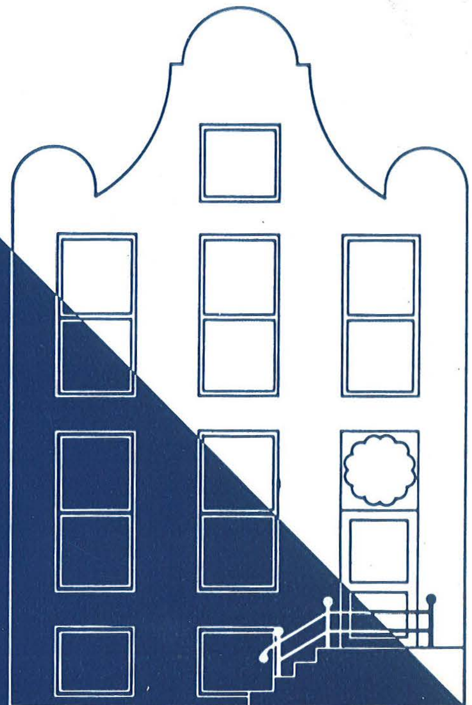
air conditioning?



R. S. SOELEMAN and P. J. HAM

1969

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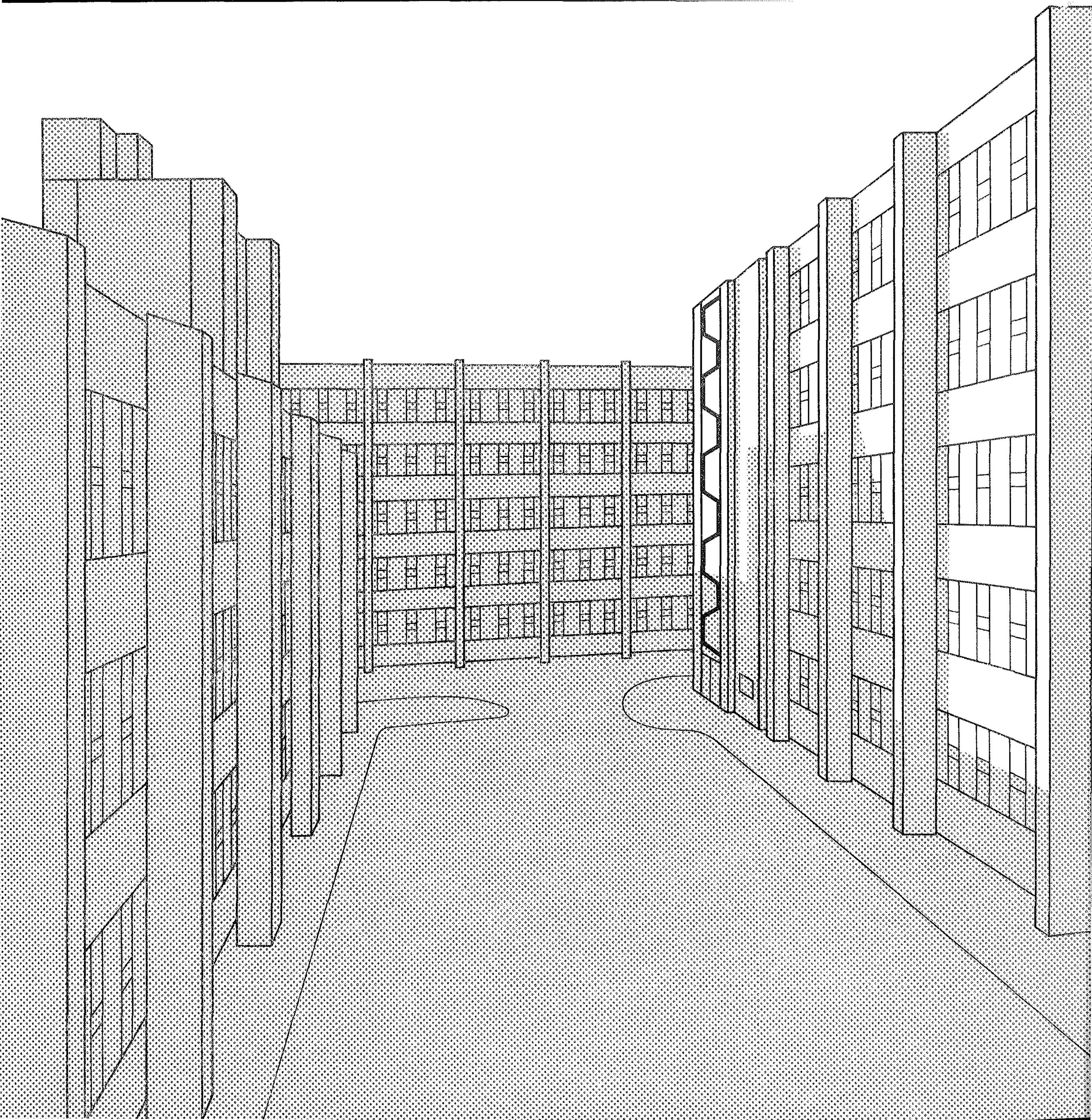

During the past years much has been published regarding the gap of knowledge that exists between Western Europe and the USA.
From various discussions on this subject, however, it is becoming apparent that this gap does not actually concern lack of knowledge with which we differ from America, but rather that it concerns a lag in applying the knowledge that has been gained.
It will only be possible to bridge this gap by modifying the present industrial policy. It will for instance be necessary to teach consultants how to apply improved techniques, being established by scientific work and then adapted to use in practice.
In order to bring this about, research workers now must have the urgent duty to express the existing problems in clear language as well as outlining the means of approach to solve them. This publication is an initial effort to this end as far as the indoor climate is concerned.
Already for a number of years this particular subject has been studied by a specialized division of the Research Institute for Public Health Engineering, which is an institute within the TNO Organization.
Subsidies received from the government enable the research work and the development of practical methods for designing installations and buildings.
It is not the idea, however, to provide a ready-made type of solution.
Some current problems are being discussed, together with an outline of the methods available to the designer of improving his design, so that it is better suited for the particular purpose. The publication therefore concerns every interested individual.
The research worker quite often serves himself of explanations that are too complicated for practical use. Besides, however, he also is of the fault-finding type, even for the work he himself performs and he will therefore appreciate constructive comment.

Ir. E. van Gunst
Head of the Indoor Climate Division

R. S. SOELEMAN and P. J. HAM

thermally warranted building and air conditioning following a test with an analogous electric model

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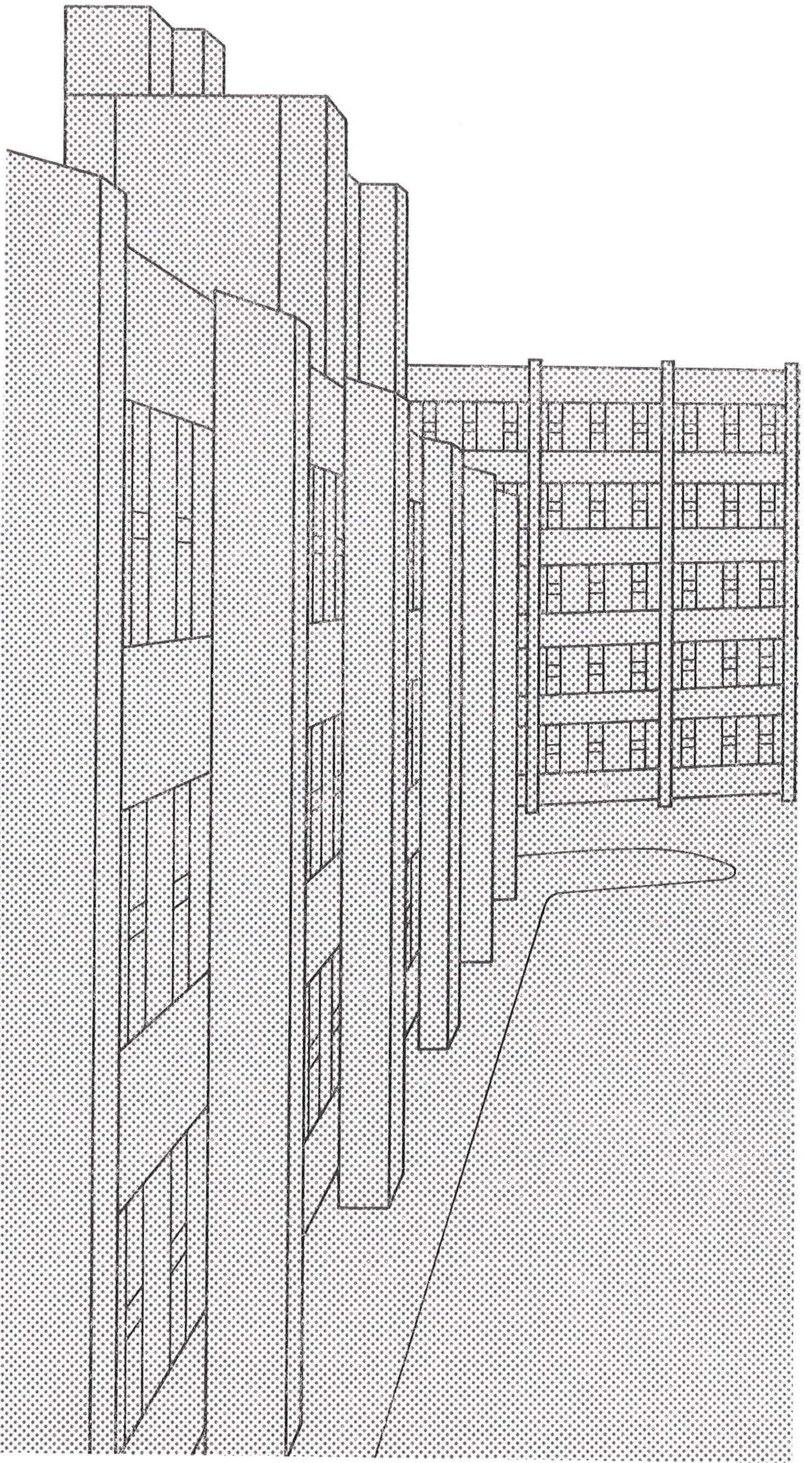


The brief should state the problems to be solved in such a way that the interrelationship between problems is clearly understood and so that the whole design team has a balanced view of the total requirement from the environmental, technical and economic aspects from the outset.

J. F. Redpath,
Director General of Research and Development
Ministry of Public Building and Works, London

contents

R. S. SOELEMAN and P. J. HAM

thermally warranted building and air conditioning following a test with an analogous electric model

RESEARCH INSTITUTE FOR PUBLIC HEALTH ENGINEERING

Primarily it is intended
that the pamphlet now in front of you
will provide information regarding
certain aspects concerning the thermal behaviour
of buildings together with the problems that arise and
the methods of approach.
It can be of particular use to those
who are regularly tackling planning and design of building projects
such as offices, laboratories, hospitals, schools and the like.
Some kind of provision for controlling the indoor climate
has become an essential feature in modern design of industrial
buildings and offices, promoting the integration
of air-conditioning installation and building.
Changing climatic conditions, the thermal inertia
of the building mass
and the fully automatic control of the air-conditioning installation
form together a complicated entity for which the
customary and approximate means of
estimating the thermal indoor conditions will fail.
Consequently your attention is
called to the use of electric models to this end.
It is also explained that the information,
achieved by this means,
is vital to a successful thermal planning procedure.

introduction

High rise buildings and the tendency to use large areas of glass will be the cause of quite a variety of problems to service engineers responsible for air-conditioning installations.

For instance, the movement of shadows that are cast by a high rise building on a near-by facade, and the consequences thereof, will comprise one particular aspect. During certain hours of the day, no sunshine will be received by some of the spaces enclosed by this wall, in contrast to the situation for other spaces.

A certain amount of knowledge of meteorology is necessary in order to establish with accuracy the contours of these shadows by one building on another one for each hour of the day and each month or year.

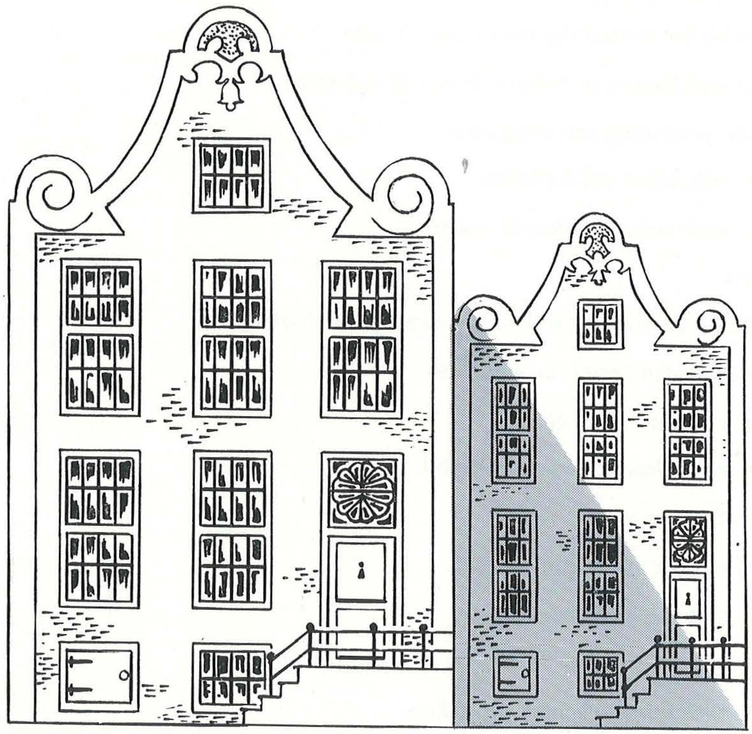
The extent to which this shadowing effect will influence the indoor temperature – a matter which is vital for the consultant in choosing between central and individual room control of an air-conditioning installation – can only be ascertained in a satisfactory manner by means of a model.

The problems caused by various types of sun shading devices on the indoor-temperature trend, are solved likewise.

The investigation by means of a model allows accurate determination of the heat storage effect of the building mass and it therefore results in a better picture of the thermal conditions that will actually exist, compared to any rule of thumb calculation in which this storage effect of building components must be ignored.

In fact the aim of each test by means of a model is to study the problem fully but on a different scale. The condition for this type of test is that the analogical reaction of the model must always reality.

In other words, the particulars that are established from the model must fully represent those that actually occur. In order to ensure this aspect, the electric model is designed in such a manner that all the rules applicable to heating are analogically introduced. Modifications to the model are easy to affect, enabling the study of the modifications in its behaviour without delay. Thus one has the disposal of an implement which can predict the thermal consequences of technical modifications on a sound basis and which requires a much shorter time to operate than that required for traditional calculating methods.



the principle of an electric model

The electric model with which the thermal behaviour of the building materials can be simulated, may be described as outlined below.

The rules which apply to building materials regarding temperature changes and subsequent heat fluxes can be established in certain types of electric circuits consisting of resistors and capacitors which provide a fully analogical relation between voltage and current.

For the majority of the materials, which are used for building and insulation, the thermal properties are sufficiently well-known and their conversion into electrical units can be performed without difficulty. The thermal properties concerned are the coefficient of heat conduction (λ-value) and the heat storage capacitors in the circuit configuration.
When the structural materials, which dictate the thermal behaviour of a building, are for the moment considered to be replaced by a combination of resistors and capacitors, one already has a fairly good idea of the electric model. The dimensions and geometric proportions of structures are represented respectively by the values selected for the resistors and capacitors in the circuit configuration.
For this model, the walls etc. are considered to be thermal barriers between two thermal conditions of the air on either side of the wall; for a particular wall therefore in fact the indoor and outdoor climate.
Heat transfer from the building structure to the air or vice versa occurs by means of radiation, convection and conduction.
The magnitude of this heat transfer will be influenced by any effect upon each of these three phenomena. When small differences between the temperatures of the structure surface and environmental air occur and in the case that the air velocities along the surface do not fluctuate excessively, it will be possible to utilize one single coefficient, the so-called surface conductance of heat transfer α. If it is expected that for the case under consideration its value will only fluctuate slightly around a specific mean value, then the heat transfer can simply be simulated by introducing a resistance in the model. When, however, it is desirable to split the effects between radiation and convection, then for each of these aspects a separate resistance, or, if necessary, a non-linear device, will be needed.
Since components of the outdoor climate such as air temperature, solar radiation etc. will vary in a non-steady manner throughout for instance the 24-hour period, these irregular features must be accounted for on the model by introducing variables which, analogically, vary in like manner. On account of these variations, the model will also be subject to changes from which the behaviour and properties of building components can be determined.
To this end, the voltages and currents are registered with respect to time and they represent the analogical amounts of temperature, solar radiation or heat flux. With the aid of a table, the necessary conversion is carried out and the data supplied from the model can be interpreted regarding the actual thermal effects on the building.

Conversion table

thermal	electrical
°C	Volts
Kcal/h	μ Amps
hour	sec.

data required for a test on a model

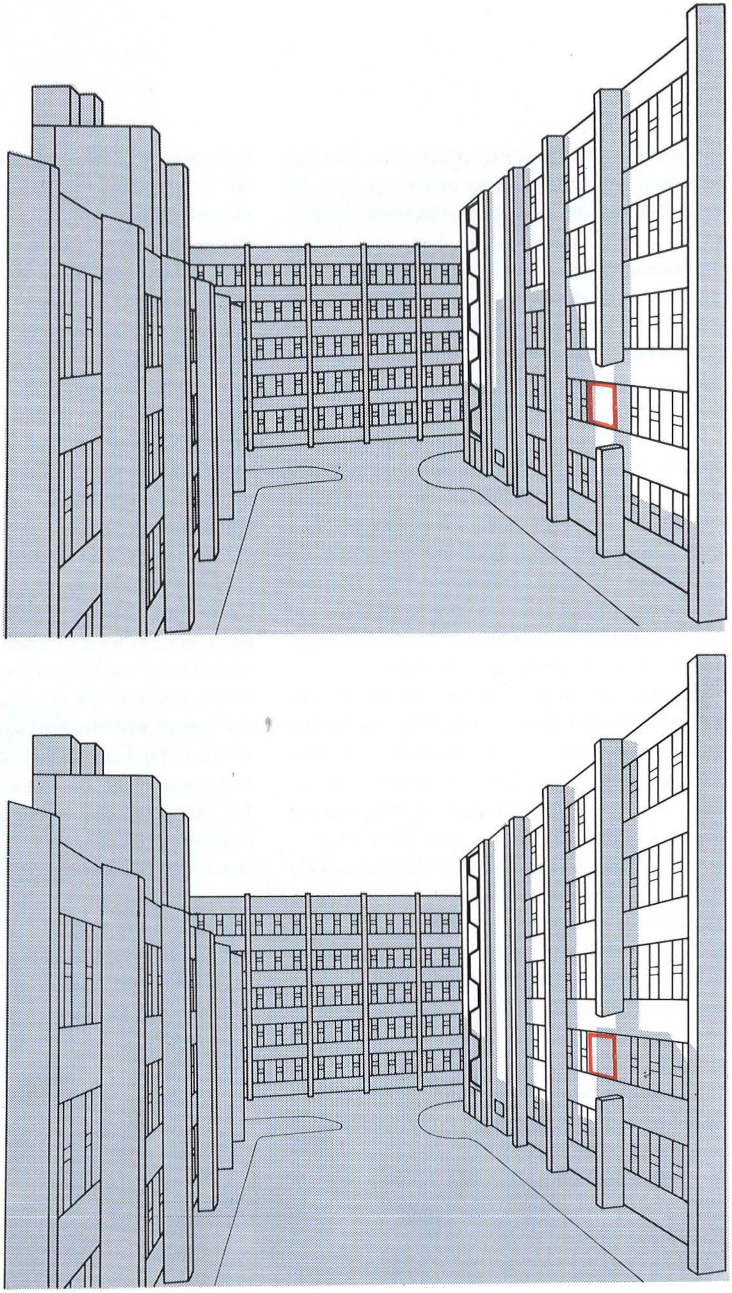


Figure 1

The relative location of the walls in a building complex is significant. The figure illustrates wall sections that are in the shadow at two different times of the same day. It is clear that the shadow area wandering over one of these walls will be of influence on the comfort experienced inside the rooms.

□ = *test room*

Orientation and location of facades and rooms

Figure 1 shows a wall facing S.S.E. of a building having 5 floors, on which shadows are cast from a 3 storey building having a projecting stairwell and elevator section. Illustrated are two different time intervals of the same day.

Depending on the day in the year, the sun will follow a particular path. This is the reason that profiles of the shadow area will always vary both horizontally and vertically.

The influence of this shadow effect in which rooms are periodically subject to either sunshine or shadow, can only be established definitely by tackling the problem with the electric model.

One of the rooms, which receives a varying amount of shadow, is shown in red on the two illustrations.

This particular room, which is on the first floor, has been subjected to a test regarding its thermal behaviour on a sunny day towards the end of October.

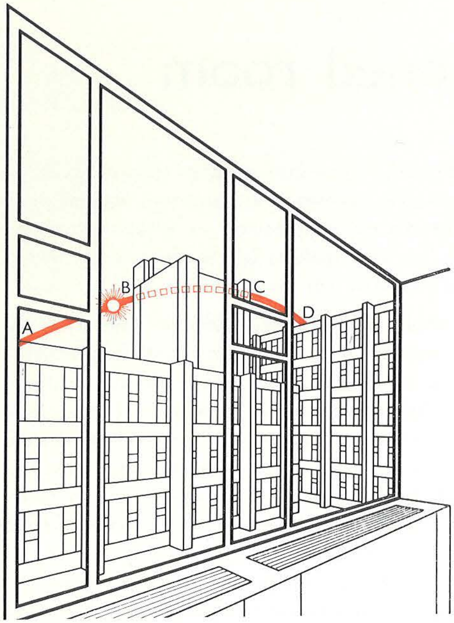
Solar exposure

The month of October was selected on account of the particular path of the sun across the sky at that time, which then is most interesting for the investigation.

This sun path, as seen from the test room, is shown in figure 2.

In general, the sun's position can be defined by two coordinates, the solar altitude (h) and the azimuth (a). These may be calculated from the latitude B (site), the declination d (date) and the hourly angle U (time interval) in the following manner:

$$\sin h = \cos U \cdot \cos B \cdot \cos d + \sin B \cdot \sin D$$
$$\sin a = \sin U \cdot \cos d / \cos h$$



Figures 2 *View from the measuring room.*

From these formulae, the sun's path as shown in figure 2 may be derived, for instance.

Transmitted solar heat radiation

From meteorological data regarding the solar radiation on a horizontal plane, it is possible to deduce theoretically (see working report C 217 of the Indoor Climate Division), the quantity of heat, radiated by the sun which is received from hour of hour by a wall facing S.S.E. towards the end of October in the case of a clear sky. It is also of prime importance that the following parameters are established individually:

- direct radiation, straight from the sun
- the so-called diffuse radiation from the sky
- reflected radiation from adjacent objects.

The building which causes the shadow effect can only screen off the direct solar radiation.
The nett quantity of solar radiation striking the room window and which contributes to heating the room air, is calculated from the shadow pattern existing at time intervals A, B, C and D (see fig. 2). The particular time intervals can be deduced from the sun's position along its path together with the geometric location of the building causing the shadow with respect to the wall under consideration.
By this means, namely, it is possible to calculate the location of the shadow area that is cast on the wall at any particular time.
The result of this calculation is illustrated in figure 3.

Building engineering data

Composition and the materials used for the building must be known. According to the previously mentioned principle it is then possible to construct an electric model representing the building segment containing the room under investigation. The volume of air in the room is 57 m^3, the average heat capacity of the surrounding walls is 256 kcal/m^3 °C, the double glazed window has a glass area of 6.4 m^2 and finally a sun shade is fitted inside the room.

Thermal irregularities

The variable outdoor temperature (fig. 4) and the changing intensity of solar radiation (fig. 3) are thermal irregularities. An additional feature is introduced when the room is air conditioned. By converting the magnitude of these irregularities to their electrical equivalents and bearing in mind the effect of the difference in scale, corresponding electrical irregularities will be created which vary analogically to reality with time.
Details of the means for converting the object's characteristics into those applicable to the model have been omitted and likewise the means of representing the irregularities by their electrical equivalents are not described. Furthermore, all clearly intricate matters concerning electronics or those regarding the manipulation of electric circuits have purposely been omitted (those interested in additional information can contact the Indoor Climate Division). Mention has only been made of features and phenomena to which attention must be called when viewed from the thermal angle. It must be stated that these data were derived from the test on the electric model, though the results could be interpreted thermally.

Figure 3
Intensity of solar radiation for a day in October and a glass area of 6.4 m^2.

--- solar radiation excluding the shadow effect
—— solar radiation including the shadow effect
---- diffuse radiation

I shadow from the low building
II shadow from the elevator housing
III shadow from the higher building and columns

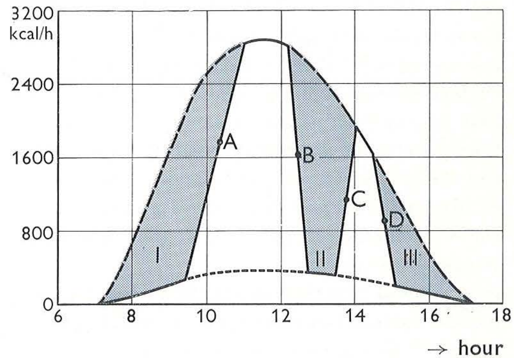
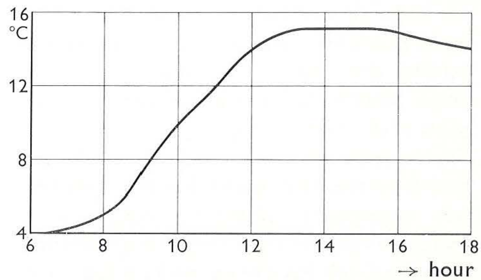


Figure 4
Outdoor temperature for a day in October.



thermal response of the non-conditioned room

Subsequent to the description given concerning the test by means of an electric model with regard to the range of temperatures encountered inside a particular room of a building complex which is subject to variable shadows during the day, the need and efficiency of such an investigation must be pointed out. A thorough investigation with the model regarding the temperatures that are encountered inside the various rooms all having the same outside wall, has produced results, which closely confirm those obtained by actual measurements.

Natural temperature behaviour

The daily temperatures encountered for the indoor air and for the wall surfaces of a room will change on account of the constantly varying outdoor temperature and solar radiation, which can be considered as external irregularities. Further changes will also result from internal heat sources such as the presence of persons, heat generating equipment, artificial lighting and the air conditioning installation. When all of these internal heat sources are absent, the room temperature will follow the natural temperature course.

It is pointed out that an estimate regarding indoor environmental conditions, which are subjected to non-steady thermal effects, must be made as accurately as possible especially when conclusions are drawn for instance regarding the means of air conditioning and when considering thermal comfort to occupants of the room.

The temperature and velocity of the air not only affect this latter aspect, but the inside surface temperatures of the surrounding walls also play a role. For a room which is conditioned in a very simple manner i.e. without cooling in summer and only heating in winter by a local heat source, very appreciable contrasts are found between the surface temperatures of window pane and walls. In this connection, a few examples may be cited:

- the high intensity of heat, radiated mainly in summer, from a sun shading device installed within the room, as this is heated by solar radiation;
- the window pane acting as a heat sink in winter. This causes heat loss on one side of persons in its vicinity.

Both these radiation effects not only result from the large temperature difference between the source of origin and the object, but they are also dependent upon the mutual geometric relation between the two i.e. by projecting the one into the other, which is established by the so-called shape factor.

Especially for cases when the anticipated temperature difference between the surface temperatures of the surrounding walls are large, the electric model will be an ideal tool for establishing their magnitude.

Temperature of the room air and the wall surfaces

As an illustration, the results of a test are presented when using the electric model to establish the thermal conditions inside the aforementioned room, which has its outer wall facing S.S.E. as shown in fig. 1. The measurements were made on a sunny day in October and the room was subjected to a varying solar load.

The air conditioning units inside the room were switched off and the room was not heated, cooled or ventilated. Even air infiltration was reduced to a minimum so that practically speaking all the conditions necessary for determining the natural temperature behaviour of the room were fulfilled. The investigation was carried out in two different ways, the first using the electric model, the second by means of thermocouples which were connected to an automatic recorder.

The data derived for the particular room from both methods were collected and compared. Figure 5 shows this comparison between the mean air temperature in the room, as established from the model and determined directly from the thermocouples. Figure 6 illustrates the instantaneous temperature readings. These can be used for estimating the thermal sensation experienced by a person inside the room.

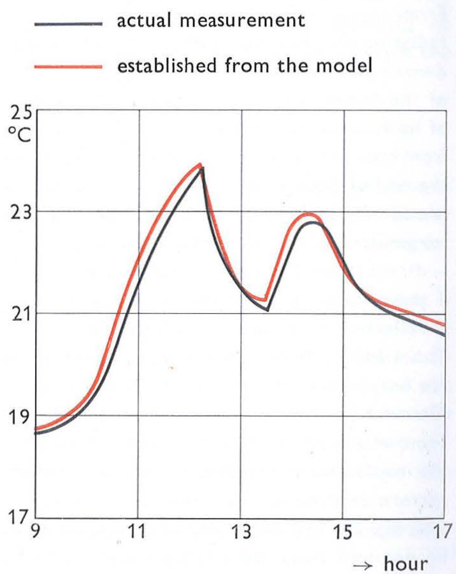
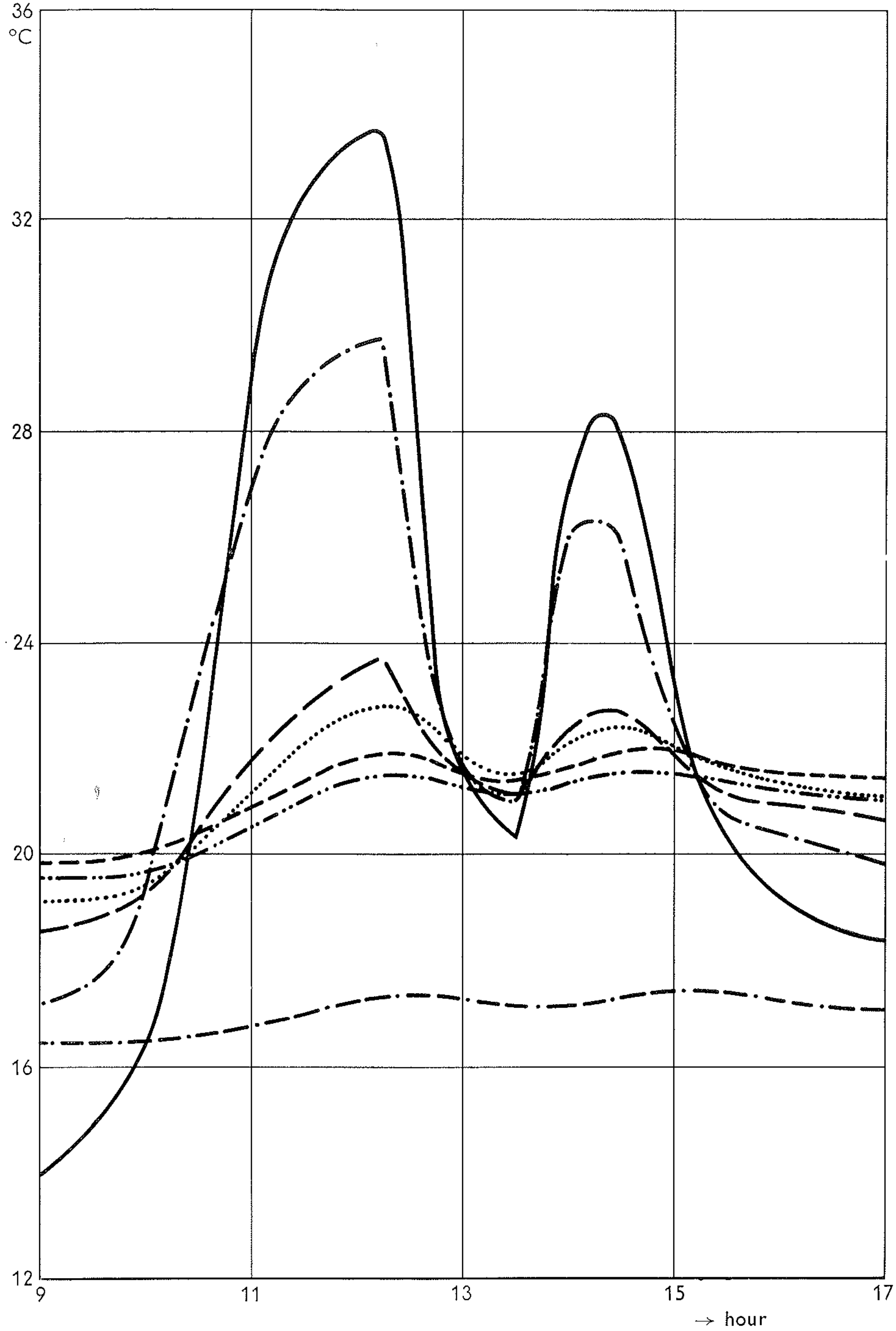


Figure 6

A full record of the temperatures which are decisive regarding the heat sensation to persons inside the rooms can readily be derived from the electric model. An example of the readings obtained is illustrated. This clearly shows the very abrupt rise and decrease of the temperatures on the face of the window pane.

glass surface
parapet surface
floor surface
ceiling surface
corridor wall surface
sunshade
room air



◀ *Figure 5*

The temperature inside the test room is markedly affected by the shadow effect. The very good agreement between temperatures, as established by actual measurement and those obtained from the electric model, is evident.

shadow effect and resulting air-conditioning problems

Its effect on the solar heat load

Figure 7 is one of the figures that have resulted from the calculation of the sections of the S.S.E. facing wall which are either exposed to the sun or in the shadow. By means of available data regarding the intensity of solar radiation for a sunny day in October, it is possible to deduce the nett quantity of solar irradiation to every floor. The particular figure illustrates the solar heat distribution which is involved. By this means it is now possible to derive the percentage intensity of solar heat to which every floor is subjected, see figure 8.

The average for the solar radiation intensity, which is denoted in this figure, is determined from the total radiation received per floor divided by the number of modules in the structure. Figure 8 already gives an indication of the most marked thermal irregularity which can occur regarding this problem. Although from the information now available one might be tempted to estimate the air temperatures in the rooms by applying traditional calculating methods, it is still preferable to establish this temperature behaviour accurately by means of the electric model if only with a view to the consequences in controlling the air-conditioning plant.

Consequences on the capacity requirements and control of the air-conditioning installation

No matter by what means one establishes the effect resulting from the shadows on the solar

= *test room*

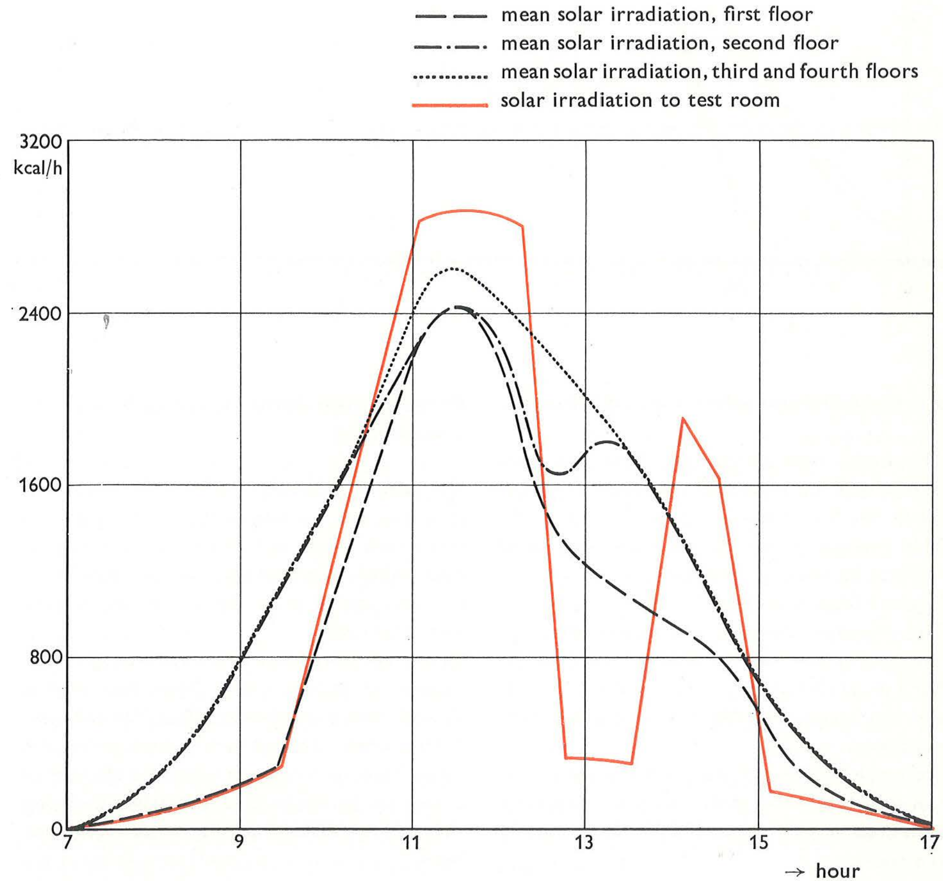
Figure 7
Example showing the complicated shadow effect.

load, it will still be necessary to reply to the following queries:

- what is the influence of the shadow effect on the thermal behaviour inside the building?
- is cooling vital and what is the capacity required?
- will central control of the air conditioning installation suffice for every room along one particular facade or is control desirable for each room or for each floor?

It is only possible to reply properly to these queries when the non-stationary thermal behaviour of the building can be determined. Since the mechanisms of heat conduction and heat storage in the structure are difficult to predict, the use of the electric model is again indicated. In order to prove this contention, the course of the temperature for the building in question was analyzed.
When considering the air conditioning of a building complex such as shown in figure 1, designers of this installation are strongly advocated to include considerations regarding the shadow effect of one structure on the other. Although it is possible to calculate this shadow effect, complicated configuration of the buildings will result in a lengthy procedure.
Since the calculation should serve to provide the correct solution, it will furthermore be necessary to investigate the extent of this shadow effect for each hour of the day and for a number of days in the year. Depending on the number of days in the year that have to be considered, this procedure will involve a vast amount of calculation work, although only a few formulae are needed. In this case therefore it appears that the use of a computer is indicated instead of labouring at the conventional calculating method.

Figure 8
From the shadow areas in fig. 7, it is possible to deduce the percentage radiation received by every floor at any moment. The figure below illustrates the solar heat radiated to individual floors expressed as the average for all the modules. The differences established between 12.00 and 15.00 hours are evident.



air conditioning?

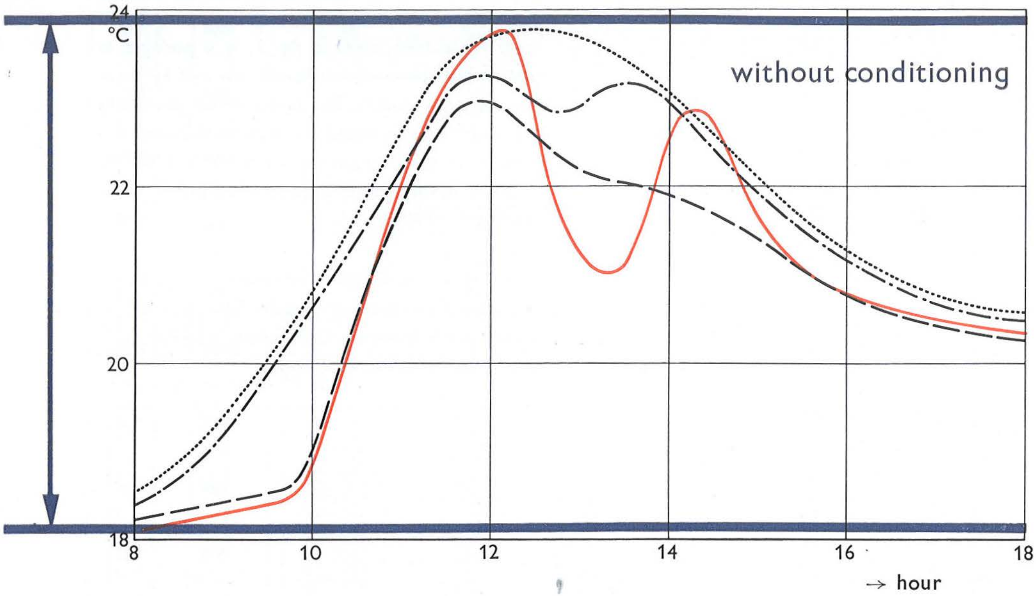


Figure 9
The results of the calculation to determine the temperature profile such as obtained from the electric model. For the solar radiation that exists in this case the average temperature of the rooms on each floor will vary as shown in the figure. For comparative purposes the temperature profile of the measuring room on the first floor is also shown.

Legend
— — return-air temp. 1st floor
—·—· return-air temp. 2nd floor

Air temperatures when not conditioned

The mean temperature per floor has been determined by means of the electric model, when the air conditioning was switched off. This average is the temperature established inside a common return duct for every floor. Figure 9 illustrates the result of this model test. The influence caused by the shadow effect on the 1st and 2nd floors is evident.
For a particular room on the 1st floor, such as the test room, the effect is even more pronounced.
From the nature of these temperature curves it is clear that their pattern is mainly caused by variations in the amount of solar heat entering the room.

Purpose, materialization and effect of conditioning

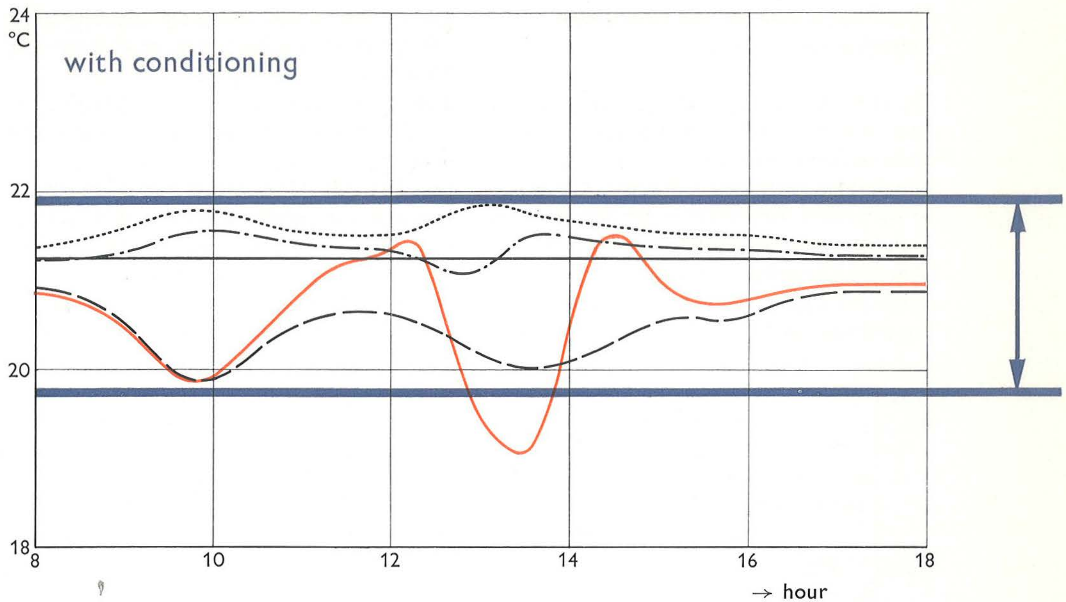
The goal of thermally conditioning the rooms in a building, is to limit the air temperature swing that would otherwise occur. The range over which this temperature is allowed to fluctuate should preferably be similar for each particular room.
Should all rooms on the wall facing S.S.E. receive an identical solar heat load, central control would definitely suffice. For this contention other internal heat sources within the room have been ignored since the effect they create can be neutralized by locally off-setting the amount of heat supply or extraction by hand.

On account of the erratic nature of the external thermal sources, control of the plant should preferably be automatic. This is not as simple as it appears to be, since on account of shadows from the adjacent building, individual rooms are always exposed to a varying quantity of solar heat. At this stage, the following query may be raised:

> Is it possible to establish the effect of this shifting shadow area on the thermal conditions of a room when the air-conditioning plant is centrally controlled?

In order to investigate this point by means of the model, the following conditions were assumed:

Figure 10
As a result of the air conditioning that was installed, the amplitude of the fluctuations in the return air temperatures originating from the various floors, when compared to the situation without air conditioning, was considerably reduced.
Although the overall temperature of the return air received from all the floors remains constant throughout the day, the figure also shows that the control system actually being used still allows the return air temperatures from individual floors to differ mutually, neither is there any reaction to a thermal change per individual room.



.... return-air temp. 3rd and 4th floor
——— return-air temp. entire facade
——— air temp. measuring room

- the return air from every room on one particular floor is exhausted by means of a communal duct. Fot the floors concerned i.e. 1st to 4th, the temperature of the return air from each floor is measured at the duct extremity
- the temperature to be controlled, is the average of those 4 return-air readings
- in order to ensure this average retains a constant value, the air conditioning installation will be called upon to extract or supply the required kilocalories of heat from or to the building.
  Since the plant is centrally controlled, every room in the building will be supplied with the same amount of either warm or chilled air.

Air temperatures when conditioned

In the case under consideration, the final result obtained from an air conditioning installation with automatic and central control is shown in figure 10.
In line with the original design specifications, it is seen that the average of the 4 temperatures remains a constant.
The temperature fluctuations in the return air between individual floors are not excessive, though they do show a difference in their mutual temperature level.
Another interesting question, that can be raised, is: what is the temperature behaviour to be expected in each individual room per floor?
From the results of the test, it has become clear that for instance for the test room on the wall facing S.S.E., the temperature fluctuates much more markedly than might be anticipated from the return air temperature from the entire floor.
The curve shown in figure 10 reveals that it is possible to have a temperature difference in excess of 2.5 °C within an hour. This fact remains unnoticed by the air conditioning system that was selected, since the average of the return air temperatures from all the rooms on that floor will not be affected. Similar fluctuations will occur in the other rooms.
It is clear that the air-conditioning procedure obtained is a compromise, the acceptability of which will have to be considered for each particular project.

Installation load for the case under investigation

On account of mutual differences in the solar heat received by the 4 floors (see figure 8) and since an identical quantity of heat is supplied or extracted by the air conditioning installation to each room, differences in the temperatures of the return air from the 4 floors are expected. The only stipulation regarding the control requires that the average of these 4 temperatures remains constant.

From a test on the model, this requirement is fulfilled when the load varies as illustrated in figure 11.
The kilocalories quoted on the ordinate of the graph in this figure actually apply to the load established for only a single room.
The fact that the mean of the 4 return air temperatures remains a constant does not necessarily imply that the temperatures in individual rooms likewise remain steady.
The particular aspect, which was also mentioned earlier in the text, must be duly recognized.

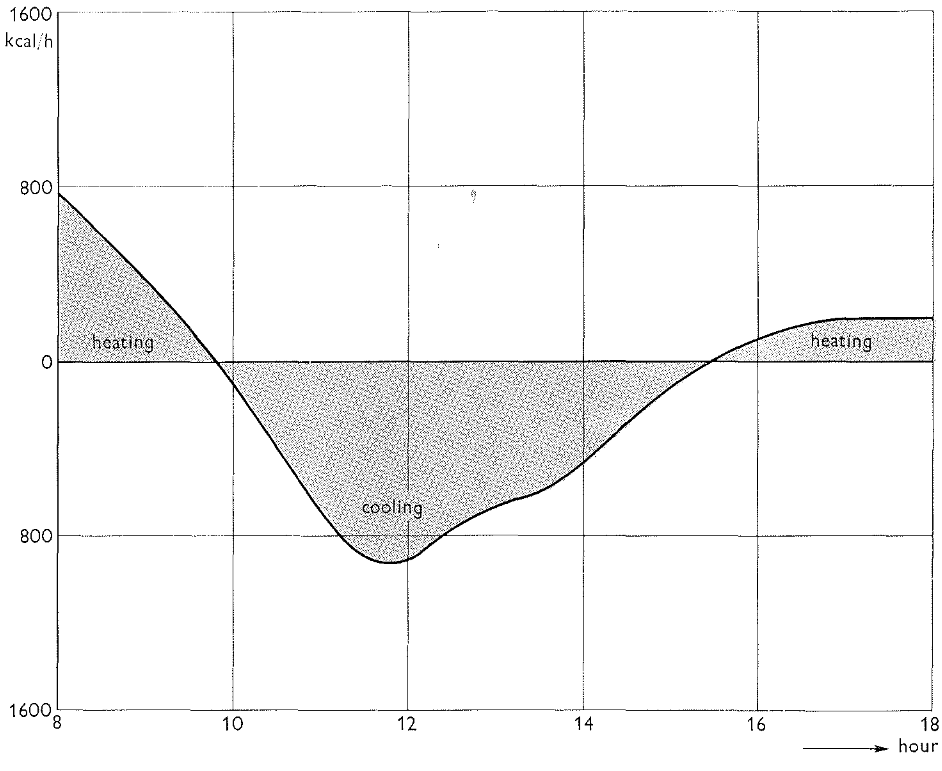
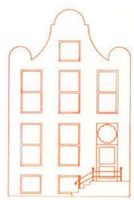


Figure 11
When in the case of a fully air conditioned building capacity control is based on the keeping constant of mean air temperatures from all the floors, the load supplied by the installation will be as illustrated. The values shown for this load apply to a single module of the building.

conclusions

Proof has been given in the preceding text that a test by means of an electric model will supply valuable information regarding non-stationary thermal characteristics. Our investigation has been confined to the effects which concern modern industrial buildings and offices, and the desirability of at least thermal conditioning these types of buildings is demonstrated. Much more generally it can be stated that all physical problems that can be described by the particular type of differential equation, can be tackled by using an electric model.
The accuracy with which actual thermal conditions are represented, is in direct relation to the precision with which the various components of the building are subdivided together with the knowledge regarding the exact behaviour of thermal irregularities.
This latter aspect is of vital importance for determining the capacity requirements of heating and cooling of the air-conditioning installation. This factor of which little was known about in the past concerns the thermal behaviour of the massive building structure when abrupt load alterations occur. These may comprise starting up the installation after having been off for the weekend and intermittent solar heat gains, due to the variable shadow effect on windows.
As already apparent from the results derived from the model test, the aforementioned aspect indicates that certain measures should be taken regarding the automatic control of the air conditioning installation. Other abrupt load variations must also be considered e.g. switching on the artificial lighting in the building or a large attendance at a meeting.
From the simulated response of the building, it is easy to decide whether it is unavoidable that the supply air will require additional cooling or whether a modification of the building design is already sufficient to warrant the desired temperature.
For that purpose one might think of introducing sun shades, whilst it is also possible to utilize building materials that are more readily suited to ensure thermal comfort in specific cases.
For the case cited in this publication, the ease with which predictory information is supplied, is very prominent, whilst the rapid and accurate means for determining this, are desirable features. It is hardly possible to make this type of prediction by conventional methods.
The method described enables to predict and evaluate the effect of any modification irrespective of whether this concerns thermal aspects of the design of the actual building, within a relatively short period of time.
The expenditure involved for a test by means of this electric model, no matter to what purpose this is utilized, is always small compared to the large capital invested by the completed building and its conditioning installation.
It is pointed out that the information, acquired by this means, not only concerns the architect and the contractor but is also of importance to management, since thermal comfort of the staff clearly affects the efficiency with which work inside the building is performed.



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