Chapter 9
Psychrometrics, Summer Conditions, and Computers

RATIONAL PSYCHROMETRIC FORMULAE

THEIR RELATION TO THE PROBLEMS OF METEOROLOGY AND OF AIR CONDITIONING

By Willis H. Carrier

ABSTRACT OF PAPER

In many industries such as the manufacture of textiles, food products, high explosives, photographic films, tobacco, etc., regulation of the humidity of the atmosphere is of great importance. This paper deals with the subject of the artificial regulation of atmospheric moisture, technically known as air conditioning. It gives a theoretical discussion of the subject in which formulae are developed for the solution of problems. These formulae are based upon the most recently determined data and in order to establish a logical basis for the presentation of these data and the derivation of the formulae, the principles governing atmospheric moisture are reviewed and the present methods of determining atmospheric humidity are discussed.

1911

DATA AND FORMULÆ

VAPOUR PRESSURE

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The vapour pressure for air at relative humidity r was computed from the relationship :—

$$x = \frac{rf}{100}$$

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The number of grains per lb. of dry air has been found as :—

$$G = 7000 \times \frac{d.f}{p-f} = \frac{4354 f}{1000 - f}$$

$$g = 7000 \times \frac{d.x}{p-x} = \frac{4354 x}{1000 - x}$$

TOTAL HEAT

This is expressed in B.T.U. per lb. of dry air (Datum 32°F.)

$$H = h_a + h_g$$

$$h_a = 0{\cdot}241\ (t - 32)$$

$$h_g = \frac{GH_s}{7000} \times \frac{g}{G}$$

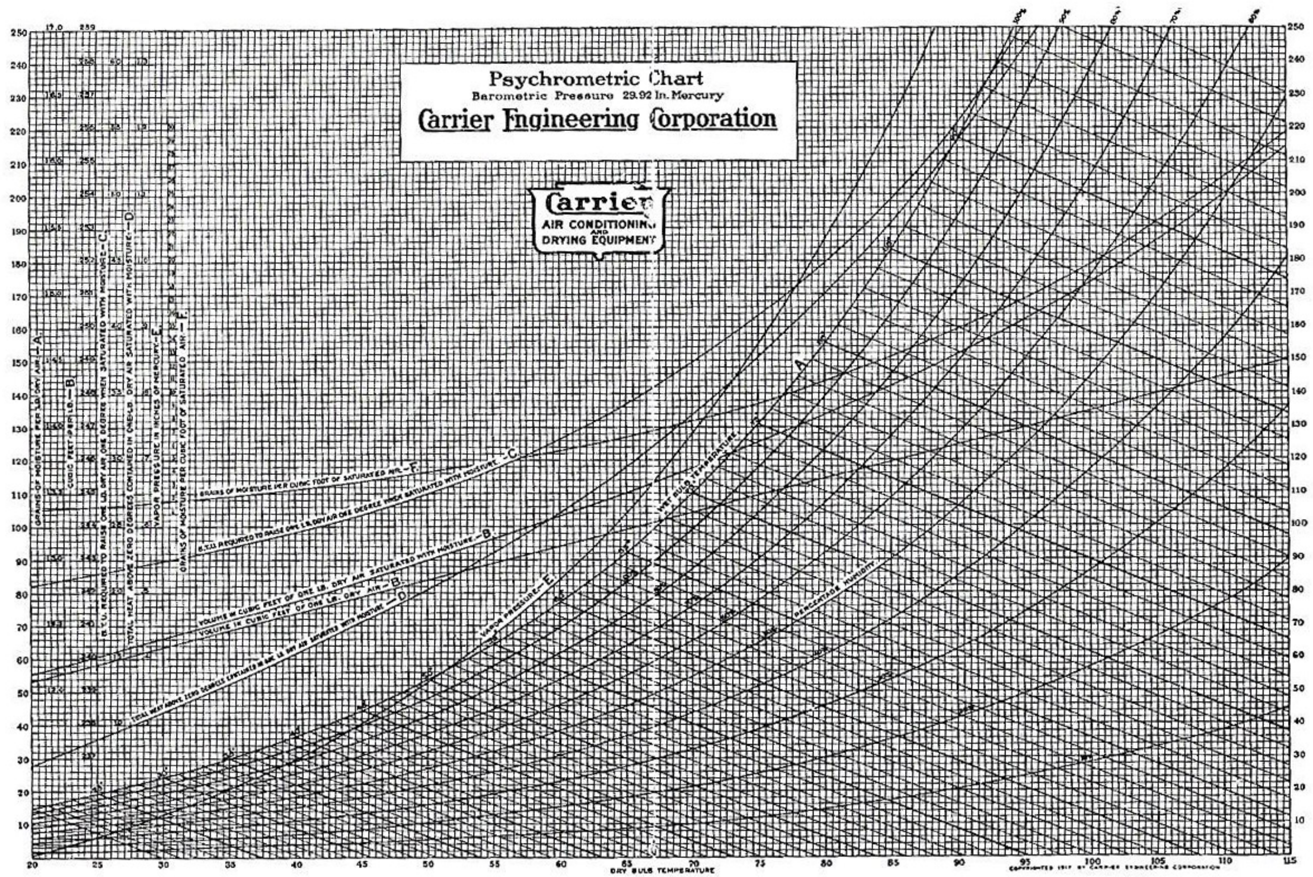
VOLUME PER LB. OF DRY AIR

$$v = \frac{RT}{P} = \frac{53{\cdot}34\ (t + 460)}{2{\cdot}0874\ (1000 - x)}$$

WET-BULB TEMPERATURE

$$t' = t - \frac{f' - x}{C}$$

The value of C corresponding to an ice-coated wet bulb has been used below 32°F. wet bulb. Care should be taken in interpolating where the change takes place : this is indicated by an asterisk.



All References to Temperature are in Degrees Fahrenheit

Dry Bulb Temperatures are represented by vertical lines with values indicated on lower edge of chart.

Wet Bulb Temperatures are represented by oblique straight lines with values indicated on the curved line marked "Wet Bulb Temperature."

Dew-Point Temperatures are represented by horizontal lines and their values indicated on the curved line marked "Wet Bulb Temperature."

Percentages of Relative Humidity are represented by converging curved lines with values indicated between the oblique straight lines for 63° and 64° wet bulb temperature.

Any two of the above properties may be found if the other two are known. First, find the point of intersection of the lines representing the given properties, and then follow through this point, the lines representing the unknown properties, and the values of the latter can be read from their respective scales.

We will be glad to mail a larger reproduction of this Chart to any Engineer, upon request.

16 17

Fig. 13.9. Carrier Psychrometric Chart (1917).

1917

13.12 SUMMER CONDITIONS

Whereas winter heat losses from a continuously warmed room may reasonably be regarded as steady, heat gains in summer are essentially periodic, being due to sunshine. Only the average value can be deduced from steady state equations. Early attempts to consider the periodic flow (e.g. by Mackay and Wright 1942-4) led to graphs for decrement factor and time lag which were too cumbersome for general use.(38)(39) These were replaced (for both peak and hourly loads) by "equivalent temperature difference" — empirically determined values to allow for solar absorption, decrement and lag, of outside walls and roofs. The Carrier Manual went further than this, and applied storage factors for the properties of the whole room (possibly found from computer).

Danter was able to simplify decrement and lag data, by demonstrating the dependence on thickness and the near-independence of density. The subsequent development of admittance theory made the calculation of peak loads, from both internal and external sources, very simple.

Mackay and Wright's most notable contribution was the concept of "sol-air" temperature:

$$t_{sol} = t_a + \alpha I R_{so}$$

an idea which has been universally adopted for use for summer calculations (Fig. 13.8).

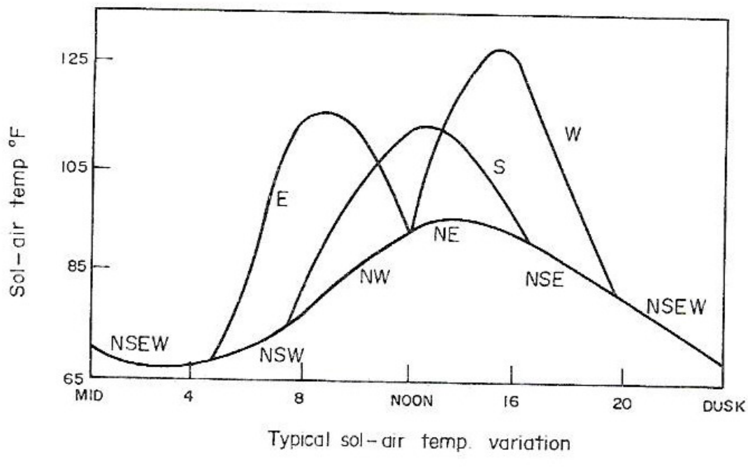
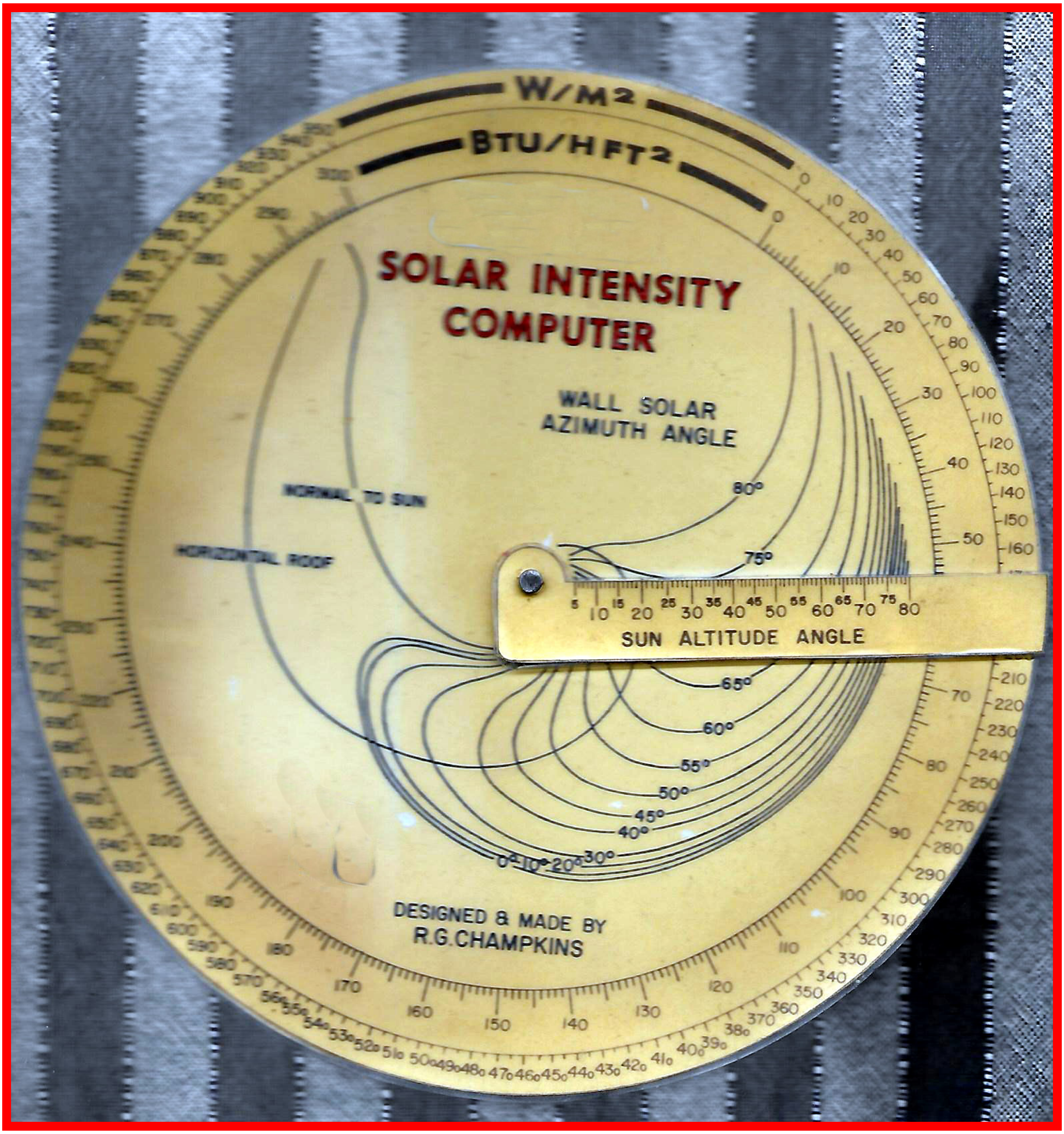


Fig. 13.8. Typical sol-air temperature variation.

Coblenz (US National Bureau of Standards) had shown the value of a white coating for the exclusion of solar heat striking a roof (i.e. a reduction of α in the sol-air temperature). A large part of the summer problem is solar gain through glazed areas. Ollett (1929) complained that he knew of no data on the transmission of sunshine through a skylight.(45) About this time, Beckett (BRS) was concerning himself with the transmission of light and heat through glass, and with methods of solar heat exclusion. There has been continuous refinement of transmission data for glass, and within recent years, the development of absorbing and reflecting glasses, to minimise the gains.



Date Unknown


WALL AZIMUTH
ANGLE COMPUTER
3. READ OFF WALL SOLAR
AZIMUTH ANGLES.
DESIGNED & MADE BY
R.G. CHAMPKINS.

1.6. WARM WEATHER DATA (GREAT BRITAIN AND OVERSEAS)

1.6.1. Selection of Outside Design Conditions

Accurate selection of outside design conditions requires meteorological information which is often not available; the selection will also depend on the application. For descriptions of methods employed in such selection reference may be made to two papers read before the Institution. [8, 9]

For use when a more detailed investigation is not possible the two sets of data which follow may be used. The first consists of a pair of maps of the United Kingdom on which are drawn isotherms of design dry- and wet-bulb temperatures reduced to mean sea level. The second sets out an approximate method which may be used for any station in the world for which Meteorological Office information is available. Tables are given which show the derived design dry- and wet-bulb temperatures for some such stations.

It will be obvious that the design figures obtained by each of the approximate methods described below are less than the extreme dry-bulb and wet-bulb temperatures which may occur. In normal air conditioning design the time lag of the building structure makes it unnecessary to design for more severe conditions. Buildings of very light construction may require special consideration. Also any installation in which it is specially important for the plant to be capable of dealing with the occasional (but inevitable and recurring) extremes will require to be designed for higher outside design temperatures.

Approximate method A

Figs. 1.18–1.19 show for England, Scotland and Wales isotherms of design dry- and wet-bulb temperatures, reduced to mean sea level, which are reached or exceeded for only 1% of the hours of summer from June to September inclusive. The two figures are reproduced from a privately published paper.[10] The information displayed on these maps was obtained from 204 weather stations for which the Meteorological Office publishes records. The maps have been produced by empirical interpolation of these weather data using a method based on that described in a paper[11] in the *Journal of Meteorology*.

To correct for altitude the isotherm figures should be reduced by 1°F for each 300 ft of elevation above sea level. This correction applies to both wet- and dry-bulb temperatures.

Approximate method B

This method uses only information readily available from the Meteorological Office.[12] The method requires a knowledge of average daily maximum dry-bulb temperature, average monthly maximum dry-bulb temperature and average daily minimum relative humidity for each month of the year.

The procedure is as follows:

(1) The month is selected which has the highest average monthly maximum dry-bulb temperature.

(2) That highest average monthly maximum dry-bulb temperature is chosen as *design dry-bulb temperature*.

(3) For the same month a vapour pressure is derived from the average daily minimum dry-bulb temperature and the average daily minimum relative humidity.

(4) That vapour pressure is associated with the design dry-bulb temperature to produce a *design wet-bulb temperature*.

The design dry-bulb and wet-bulb temperatures obtained by this method for a number of stations throughout the world are set out in Tables 1.7 Europe; 1.8 Africa; 1.9 Asia; 1.10 Australasia; 1.11 North America; 1.12 South America.

The last column in these Tables states the average diurnal range of dry-bulb temperature for the selected month. This enables a rough assessment to be made of overnight minimum conditions associated with the design maximum temperatures. Such information is useful when designing for heavy buildings so that advantage can be taken of low night temperatures if they occur.

1965

DRY-BULB ISOTHERMS (*Approximate method A on page 10*)

Fig. 1.18. Summer External Design Dry-bulb Isotherms for England, Scotland and Wales
The isotherms are exceeded for only 1% of the hours of summer from June to September inclusive. To correct for altitude, reduce by 1°F for each 300 ft above sea level.

(*Reproduced by kind permission of Head Wrightson Processes Ltd.*)

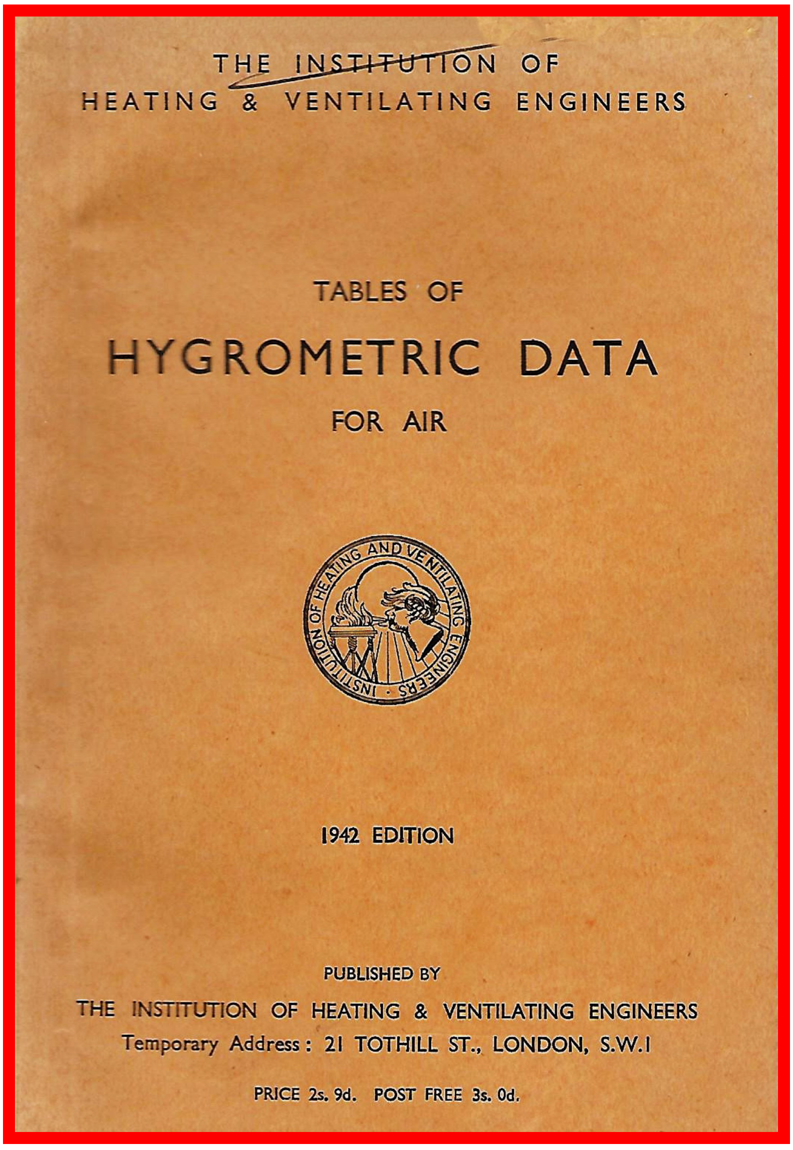
1965

13.13 PSYCHROMETRIC DATA

The basic data for air conditioning calculations are found in tables of the physical properties of moist air — the psychrometric tables. Boyle (1659) established the relation between air temperature and density, and in 1800 John Dalton formulated the laws governing the vapour pressure of water in air. James Apjohn (an Irish Chemist) propounded the theory of adiabatic absorption of water by air in 1835-6, though he was unable to verify it. This was that the wet bulb temperature was related to the total heat (enthalpy) of moist air.

The first attempt to tabulate psychrometric data was made in 1847 by the English meteorologist James Glaisher, who computed reliable tables of the stationary wet- and dry-bulb temperatures. It is, no doubt, these tables which were used for the Cotton Cloth Factories Act of 1889, and which were praised by Wilson. They were followed by Ferrel's empirical formulae (1886) on which the US Weather Bureau psychrometric tables were based. In 1900, Professor Marrin produced new tables, though these too seem to have been based on empirical formulae.

Box[12] gave tables of the properties of moist air. Carpenter used these tables in 1910, but he also gave humidity data from the US Department of Agriculture. Poynting and Thomson ("Heat")[48] refer to Hazen's tables, published in Washington, and which are based on a simplified version of Apjohn's formula.



1942

DATA AND FORMULÆ

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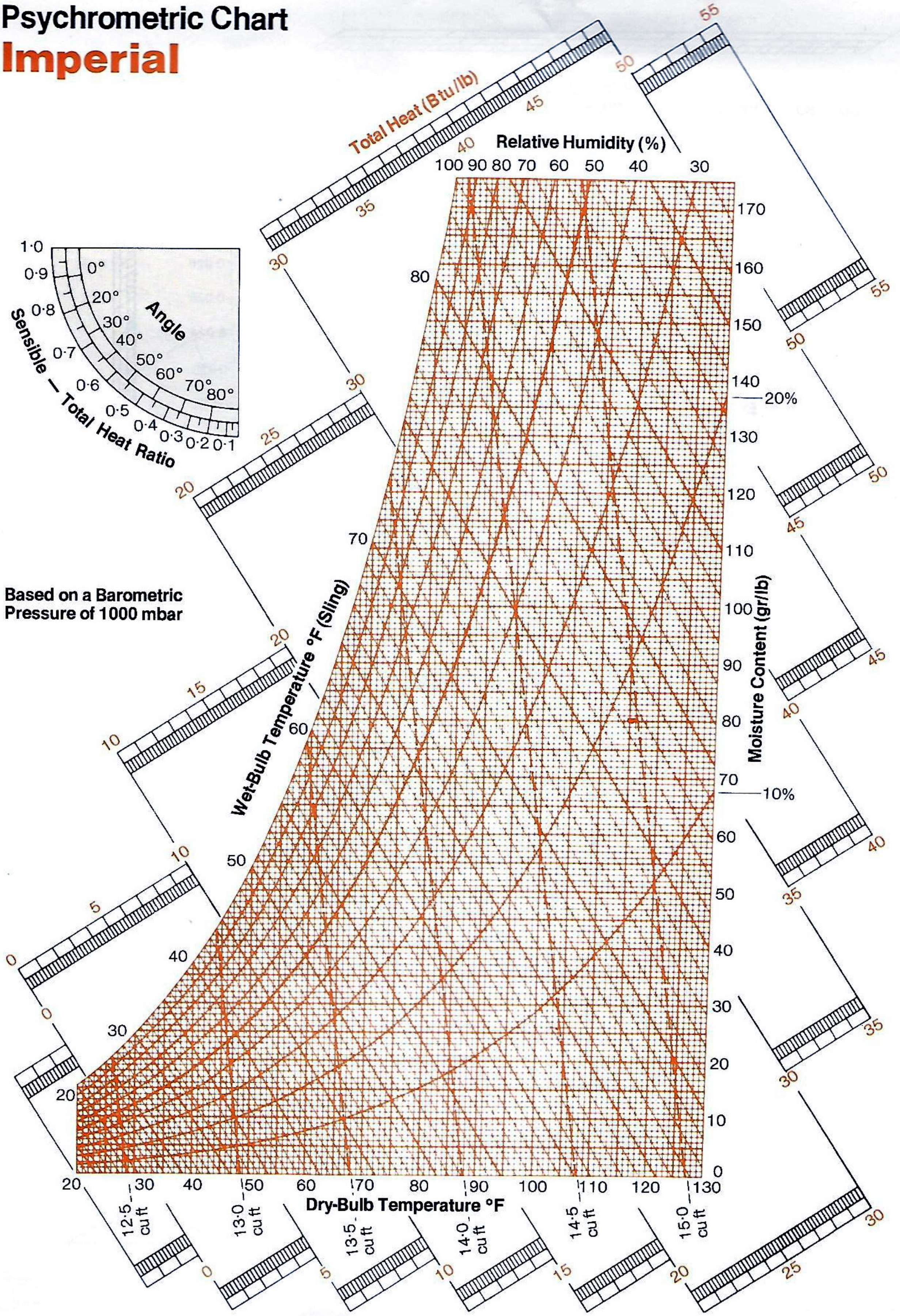
71° F.

Relative Humidity Per Cent.	Vapour Pressure in Millibars	Dew Point in Deg. F.	Per Pound of Dry Air			Wet Bulb	
			Moisture in Grains	Total Heat B.T.U.	Volume in Cu. Ft.	Screen Deg. F.	Sling Deg. F.
100	25·92	71·0	115·9	27·47	13·93	71·0	71·0
96	24·88	69·8	111·1	26·73	13·92	70·2	70·2
92	23·85	68·6	106·4	25·99	13·90	69·4	69·3
88	22·81	67·3	101·6	25·24	13·89	68·6	68·5
84	21·77	65·9	96·9	24·50	13·87	67·8	67·6
80	20·74	64·5	92·2	23·78	13·86	66·9	66·7
76	19·70	63·1	87·5	23·04	13·84	66·1	65·8
72	18·66	61·5	82·8	22·32	13·83	65·2	64·8
70	18·14	60·7	80·4	21·96	13·82	64·8	64·3
68	17·63	59·9	78·1	21·58	13·82	64·3	63·9
66	17·11	59·1	75·7	21·22	13·81	63·9	63·4
64	16·59	58·2	73·4	20·85	13·80	63·4	62·9
62	16·07	57·3	71·1	20·49	13·80	63·0	62·4
60	15·55	56·4	68·8	20·13	13·79	62·5	61·9
58	15·03	55·5	66·4	19·77	13·78	62·0	61·4
56	14·52	54·5	64·1	19·41	13·77	61·6	60·9
54	14·00	53·5	61·8	19·03	13·77	61·1	60·4
52	13·48	52·5	59·5	18·67	13·76	60·6	59·9
50	12·96	51·4	57·2	18·31	13·75	60·2	59·4
48	12·44	50·3	54·9	17·96	13·74	59·7	58·8
46	11·92	49·2	52·5	17·60	13·74	59·2	58·3
44	11·40	48·0	50·2	17·24	13·73	58·7	57·7
42	10·89	46·8	47·9	16·88	13·72	58·2	57·2
40	10·37	45·5	45·6	16·52	13·71	57·7	56·7
38	9·85	44·1	43·3	16·16	13·71	57·2	56·1
36	9·33	42·7	41·0	15·80	13·70	56·7	55·5
34	8·81	41·3	38·7	15·43	13·70	56·2	55·0
32	8·29	39·7	36·4	15·07	13·69	55·6	54·4
30	7·78	38·1	34·1	14·71	13·68	55·1	53·8
28	7·26	36·3	31·8	14·37	13·67	54·6	53·2
24	6·22	32·4	27·3	13·65	13·66	53·5	52·0
20	5·18	28·4	22·7	12·94	13·64	52·4	50·8
16	4·15	23·6	18·1	12·22	13·63	51·3	49·6
12	3·11	17·5	13·6	11·51	13·61	50·2	48·3
8	2·07	9·2	9·0	10·81	13·60	49·0	47·0
4	1·04	− 4·2	4·5	10·10	13·59	47·8	45·6
0	0	—	0	9·40	13·57	46·6	44·3

1942

Psychrometric Chart
Imperial



IHVE

According to Ingels,[32] Willis Carrier was dissatisfied with the basis of the US Weather Bureau tables, and when in 1906 he wrote a catalogue for the Buffalo Forge Company, he included a new hygrometric chart. This was later refined, and in 1911 he published a paper entitled "Rational Psychrometric Formulae" which brought him international fame.[15] It dealt with sensible, latent and total heat, enunciated the theory of adiabatic saturation, and showed the relationship between the dry bulb, wet bulb and dewpoint temperatures of the air. The formulae presented by Carrier and his accompanying psychrometric charts (Fig. 13.9) were rapidly to become the authoritative basis for all of the fundamental calculations necessary for the design of air conditioning systems and equipment.

A psychrometric chart relating moisture content and RH was published by Marr in Germany in 1915. The Mollier diagram was devised in 1904, (Z.V.D.I.) and has been used as the basis of refrigerant tables and charts as well. Goff and Gratch (University of Pennsylvania) re-examined the bases of psychrometry in 1945, and produced the most accurate tables which now exist. Their work has been adopted by ASHRAE in America and by CIBS in Britain for their hygrometric tables.

13.14 THE COMPUTER REVOLUTION

The calculations required for the design of building services have grown enormously in complexity within recent years. When it was possible to consider only the maximum steady-state heat loss, and the steady flow of fluids in pipes, and when engineers could deal with each service separately, little other than simple arithmetic processes and the use of tables was necessary.

Changes in building construction (the advent of light structures), increasing variety of methods of heating, including air conditioning, each with differing characteristics (of which warm-air heating and floor-warming are extreme examples), the wider use of controls, and the economic forces all combined to render the steady state approach inadequate, and to require closer estimates of annual energy use.

The mathematical theory which was necessary for the solution of non-steady heat flow problems had been available since Fourier's classic work, about 1820. The practical application of the theory to the heating of buildings and to system analysis waited upon Heaviside's operational calculus, the Laplace transform and matrix algebra. There was also very limited knowledge of the thermal properties of building materials, of ventilation rates and of meteorological data.

But even when all the data and mathematical techniques were available, any solution of the probems was a tedious business.

Initially, recourse was had to mechanical means (Nessi and Nisolle[44]) of solving equations. About 1948, a graphical solution, based on an analogy with electrical conduction, and which could be applied to multi-layer structures, was provided by Marmet.[40]
The relaxation method of Southwell, and the Hardy-Cross finite difference method were also used in research studies.

None of these methods was suitable for use as a routine design procedure. They were, however, valuable in enabling quasi-empirical tables to be prepared (e.g. for intermittent heating allowances).

This paper was delivered at a Sessional Meeting of the Institution of Heating and Ventilating Engineers on Thursday, 9th November, 1967, at the National College, London.

New Developments In The Computer-Design Of Air-Conditioning Systems

By A. W. Boeke

The role of the computer in air-conditioning

When planning a new building such as an office block, hotel or school, the client is often faced with decisions having wide economic implications without any opportunity to base these decisions on precise cost data.

The cost of the purely aesthetic attributes of a building, its architectural form, cladding and so forth can often be estimated fairly well. But the investment and running costs involved in the less readily defined characteristics, such as the degree of indoor air comfort, have proved in practice to be very difficult to calculate. The standard of air-conditioning can, however, now be defined and costed with an accuracy and speed that was inconceivable before the advent of electronic data processing. There is no doubt of the importance to building owners and their consultants, in conjunction with the architect, of being able to ascertain speedily and dependably the degree of comfort, flexibility and controllability that can be obtained with various air-conditioning systems, the ways in which the design and construction of the building will affect these features, and the investment, running costs and space requirements implicit in the different alternatives.

Some of the information required can be calculated at an acceptable speed without recourse to a computer, though only by the adoption of many rules of thumb and approximations. Other factors, such as the effect of window area on the total running costs, are hardly ever calculated in the course of the conventional planning routine for large buildings, due to the deterring scope of such calculations.

As an example of the complexity of these problems, consider the determination of the refrigeration capacity required for an air-conditioning installation. Fig. 1 shows an example of the irregular variations in heat deficit and excess in an ordinary office module with south-east aspect, on a sunny day. The walls of a building may also be shadowed at times by neighbouring buildings and, in such cases, the load curve shown here would vary for different parts of the same external wall, by relative amounts varying according to the time of day. In order to determine the maximum total cooling requirement for the building such curves must be produced for all external walls or parts thereof and the net sum added to the refrigeration capacity which may be required for cooling and dehumidifying the ventilation air. This procedure must be repeated for a large number of points in time throughout the year in order finally to determine the maximum capacity required.

Survey of computer programmes hitherto prepared

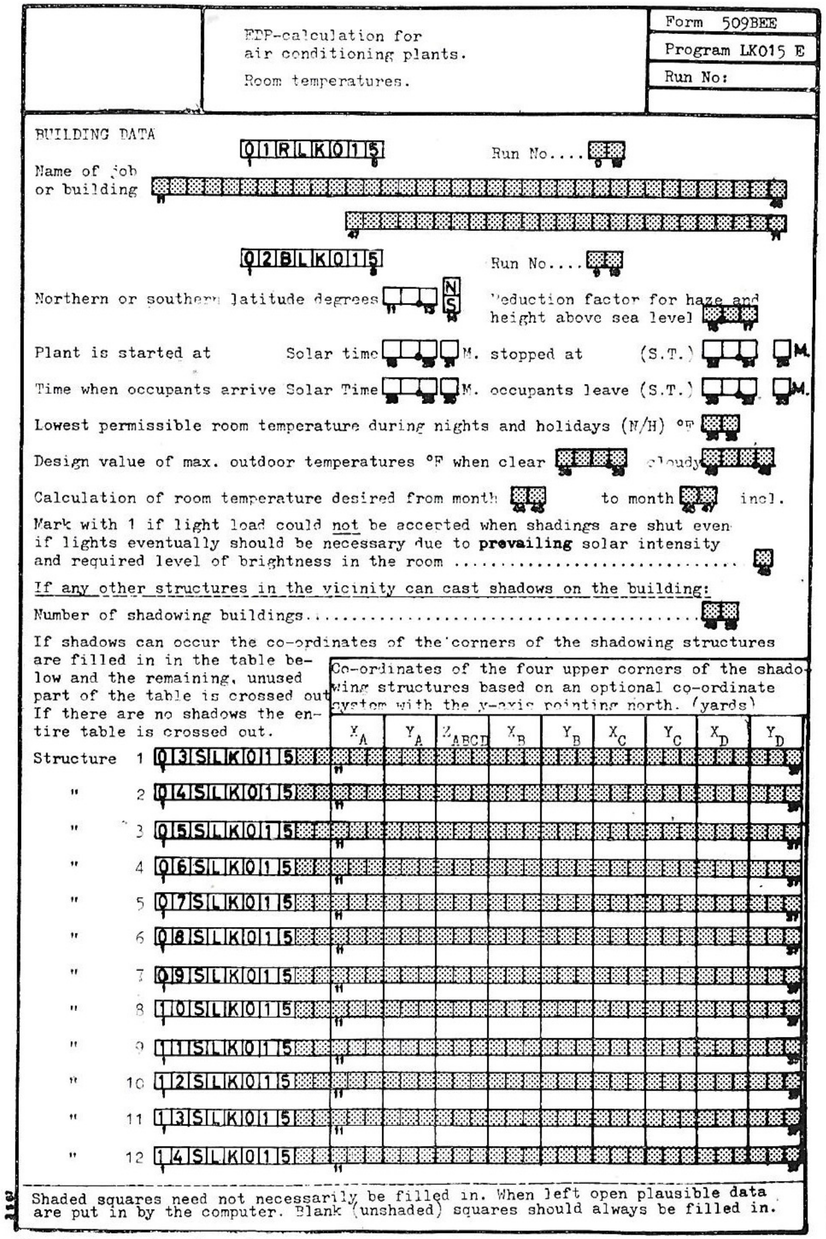
A number of types of computer programme are necessary if the costing of various alternatives and the influence of different factors are to be accurately and economically estimated in a practical fashion. The first question posed is often whether an air-conditioning installation is in fact necessary, or whether an acceptable indoor climate could be maintained by a simple ventilation system. The prime decisive factor in this case is the temperature attained in the rooms during the hottest part of the year. There is therefore need for a computer programme (1) to predict the course of daily temperature variations in a room with given structural characteristics and based on specified conditions as regards the use of the building and the local outdoor climate. Consideration must also be given to the volume of supply ventilation air and its temperature.

If the need for an air-conditioning installation is found to exist, the following types of programme will be required for the computer design of the plant and the calculation of operating costs:

(2) A programme giving the heating and cooling requirement per module for all external walls or zones of the building, regardless of the type of installation which will be employed to meet these requirements.

(3) Programmes which, on the basis of the results yielded by (2), indicate the corresponding capacities, etc., of the various feasible types of air-conditioning installation, calculate the annual energy consumption and tabulate operating characteristics, together with an indication of the comfort standard achieved under normal and extreme weather conditions.

1967



EDP-calculation for air conditioning plants.
Room temperatures.

Form 509BEE
Program LK015 E
Run No:

BUILDING DATA

01RLK015 Run No....

Name of job or building

02BLK015 Run No....

Northern or southern latitude degrees N/S

Reduction factor for haze and height above sea level

Plant is started at Solar time M. stopped at (S.T.) M.

Time when occupants arrive Solar Time M. occupants leave (S.T.) M.

Lowest permissible room temperature during nights and holidays (N/H) °F

Design value of max. outdoor temperatures °F when clear cloudy

Calculation of room temperature desired from month to month incl.

Mark with 1 if light load could not be accepted when shadings are shut even if lights eventually should be necessary due to **prevailing** solar intensity and required level of brightness in the room ....

If any other structures in the vicinity can cast shadows on the building:

Number of shadowing buildings..

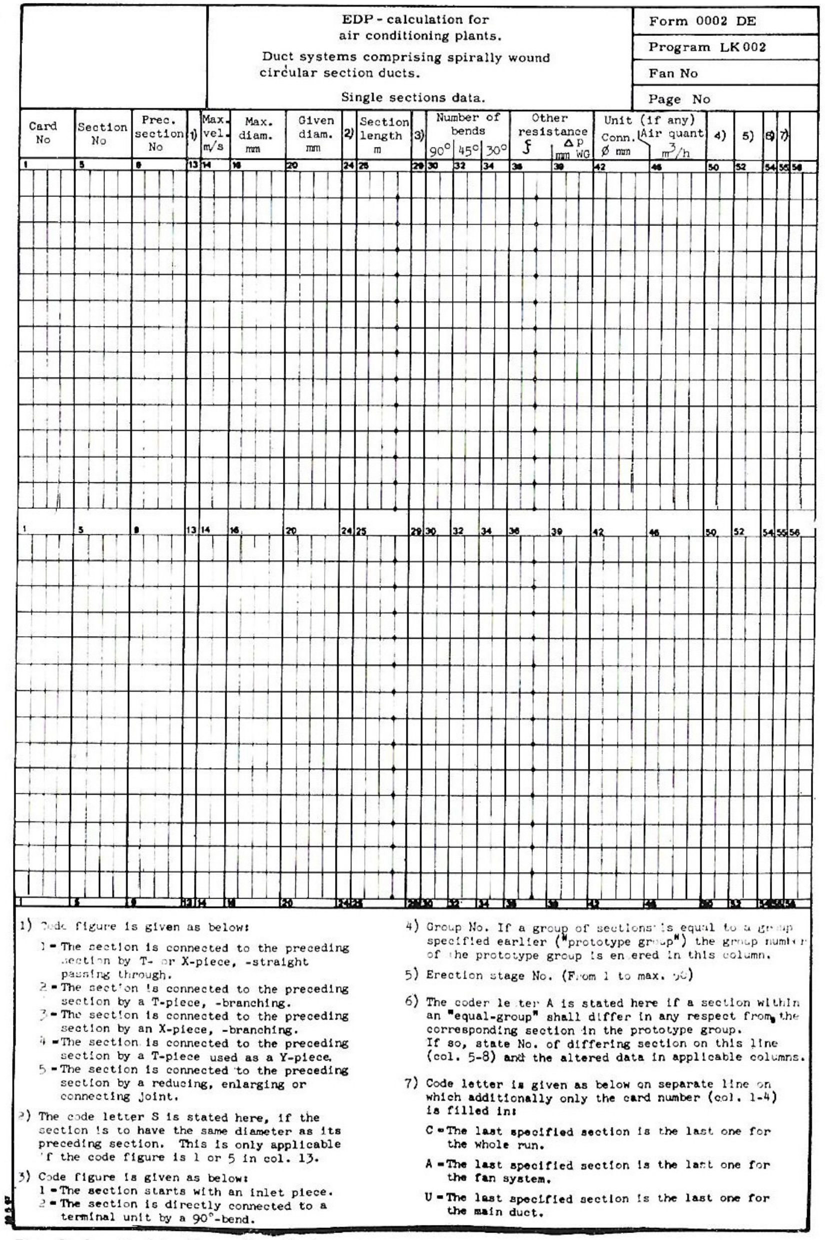
If shadows can occur the co-ordinates of the corners of the shadowing structures are filled in in the table below and the remaining, unused part of the table is crossed out. If there are no shadows the entire table is crossed out.

Co-ordinates of the four upper corners of the shadowing structures based on an optional co-ordinate system with the y-axis pointing north. (yards)

		X_A	Y_A	Z_{ABCD}	X_B	Y_B	X_C	Y_C	X_D	Y_D
Structure 1	03SLK015									
" 2	04SLK015									
" 3	05SLK015									
" 4	06SLK015									
" 5	07SLK015									
" 6	08SLK015									
" 7	09SLK015									
" 8	10SLK015									
" 9	11SLK015									
" 10	12SLK015									
" 11	13SLK015									
" 12	14SLK015									

Shaded squares need not necessarily be filled in. When left open plausible data are put in by the computer. Blank (unshaded) squares should always be filled in.

Fig. 7. Input data form for temperature programme



EDP - calculation for air conditioning plants.
Duct systems comprising spirally wound circular section ducts.
Single sections data.

Form 0002 DE
Program LK 002
Fan No
Page No

Card No	Section No	Prec. section No	1)	Max. vel. m/s	Max. diam. mm	Given diam. mm	2)	Section length m	3)	Number of bends 90°	45°	30°	Other resistance ζ	Δp mm WG	Unit (if any) Conn. ø mm	Air quant m³/h	4)	5)	6)	7)

1) Code figure is given as below:
1 = The section is connected to the preceding section by T- or X-piece, -straight passing through.
2 = The section is connected to the preceding section by a T-piece, -branching.
3 = The section is connected to the preceding section by an X-piece, -branching.
4 = The section is connected to the preceding section by a T-piece used as a Y-piece.
5 = The section is connected to the preceding section by a reducing, enlarging or connecting joint.

2) The code letter S is stated here, if the section is to have the same diameter as its preceding section. This is only applicable if the code figure is 1 or 5 in col. 13.

3) Code figure is given as below:
1 = The section starts with an inlet piece.
2 = The section is directly connected to a terminal unit by a 90°-bend.

4) Group No. If a group of sections is equal to a group specified earlier ("prototype group") the group number of the prototype group is entered in this column.

5) Erection stage No. (From 1 to max. 90)

6) The code letter A is stated here if a section within an "equal-group" shall differ in any respect from the corresponding section in the prototype group. If so, state No. of differing section on this line (col. 5-8) and the altered data in applicable columns.

7) Code letter is given as below on separate line on which additionally only the card number (col. 1-4) is filled in:
C = The last specified section is the last one for the whole run.
A = The last specified section is the last one for the fan system.
U = The last specified section is the last one for the main duct.

Fig. 8. Input data form for duct system programme

1967

At about the same time, analogue models (Beuken, Paschkis *et al.*) were developed for steady-state situations, and applied to heat-loss problems. Resistance-capacity networks were also employed to some extent in research. An analogue computer for ventilation networks in mines was constructed by Scott *ca.* 1953 — the noteworthy feature being the use of electric lamps instead of simple resistors to give a power-law relationship between pressure and velocity. As with the mathematical tools, these analogues were unsuited for design use, but were used to derive empirical formulae and tables from special cases (e.g. BRE work on floor warming).

The invention of the differential analyser and its development into the electronic computer enabled the complex equations to be quickly solved. In our case, it is the ability to solve a number of simultaneous differential equations, with complicated initial and boundary conditions (rather than a capability of handling otherwise intractable equations) which is significant. The high cost of the first computers restricted them to research laboratories. As the cost fell, they became more widespread, though few were in use in industrial design offices. Nevertheless, engineering graduates learned to program in their university courses and gained experience on the university computers. There began the publication of a stream of programs which would enable routine calculations of heat loss or fluid networks to be carried out in a fraction of the time required for manual computation. The way was open for optimisation — the repetition of a calculation with a range of parameters, with the final selection of one solution giving, for example, minimum cost, or minimum energy.

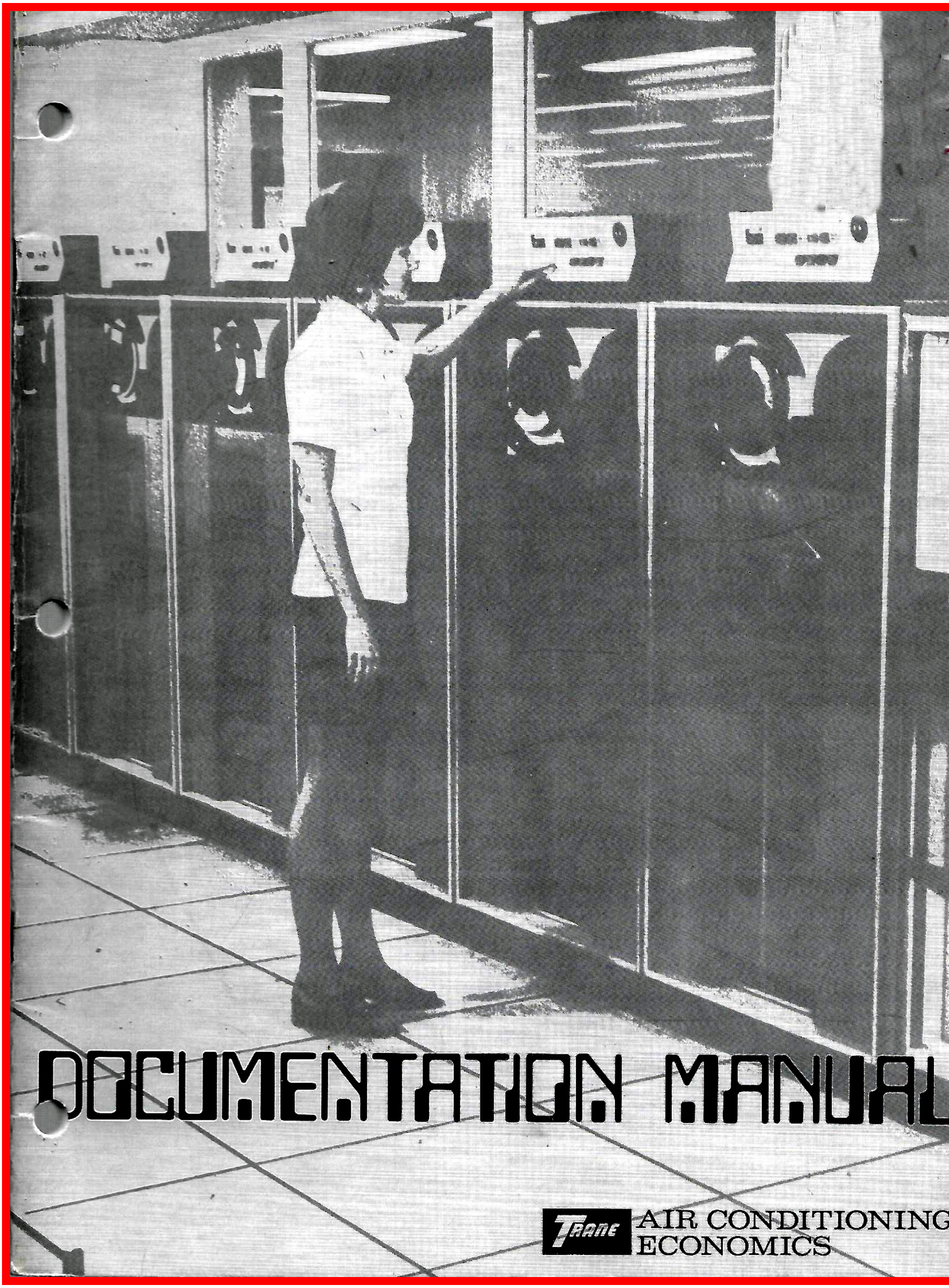
An iterative mathematical solution for fluid networks was developed by Howard(31) in 1957 while still a student at the National College for Heating, Ventilating, Refrigeration and Fan Engineering in London. Computer solutions of typical problems were successfully achieved, and Howard indicated how an optimum economic layout could be found. The first British commercial application of this type of program was in 1968, by M. B. Swain of Rosser and Russell. in cooperation with ICT.

A comprehensive range of air conditioning load and system design programs was introduced in the early 1960's by the Swedish company Fläkt (SF Air Treatment). In 1965, the American magazine *Heating, Piping, Air Conditioning* sponsored a major conference in Chicago on the use of computers, which covered a variety of topics including calculating heating and cooling loads, system simulation, energy studies, duct sizing and equipment selection. Over the next few years, many manufacturers have developed computerised equipment selection programs for refrigeration machines, heating and cooling coils and air handling plant (notably Carrier, Trane and Fläkt).

The art is perhaps most advanced in North America and in France, where a nation-wide computer network now exists, having been in operation since about 1970. A designer anywhere in France can feed specific data into a terminal connected to a central computer, and receive, as output, the appropriate design. Up to the present time, many thousands of radiator heating systems have been sized by the network. The French programs are compatible, that is, the output of one, say a heat-loss program, can serve immediately as the input to the next (e.g. pipe-sizing). The ultimate objective is a program which starts with the architect's conception, works through the services design, and whose output is an ordering list and a critical path analysis for the installation process.

A more recent innovation is the interactive display unit, in which a designer can adjust a parameter and immediately see, on a screen, the effect of the alteration.

The use of computers is not confined to engineering problems. Indeed, in general industry, this may well be a minor role. Apart from handling financial matters, however, it has found application in management, in particular in stock control and project management. Critical path networks were described at a computer conference in 1959: these identify those parts of a project where timing is critical. For



DOCUMENTATION MANUAL

TRANE AIR CONDITIONING ECONOMICS

1973

introduction

The purpose of the Trane Air Conditioning Economics Program is to aid the user, through the comparison of alternative design approaches, to establish an optimum relationship between the first and operating costs of air conditioning.

Accurate economic evaluation of the alternatives offered by various system combinations and those aspects of building design that affect air conditioning performance has always been a difficult chore. Not because the necessary design and economic data is not well defined, but because of the almost endless amount of computation required.

Toward the solution of this problem, the Trane Air Conditioning Economics Program uses ASHRAE and other industry standard techniques to simulate the performances of alternative building air conditioning systems to arrive at the operating costs of each. The total economics of the alternatives are then analyzed and compared, providing the user with meaningful criteria for economic decision.

The developmental goals established for this program were:

Credibility,
Input Simplicity and
Flexibility.

Only ASHRAE Guide techniques and accepted industry practices are used as the basis for all calculations and procedures.

As each phase of the program was completed, both the engineering and economic analysis techniques used were verified by leading consultants in the particular fields involved.

The second objective, simplicity, was met by developing a program that requires the input of only a minimum amount of conventional engineering and economic data by the user.

Flexibility is provided through the use of many program modules. The modular approach permits easy access to the program for revision, expansion and updating of data and data handling processes.

(Figure 1) The program is broken down into five major phases:

Load Phase,
Design Phase,
System Simulation Phase,
Equipment Simulation Phase and
Economic Analysis Phase

Each phase requires certain input by the user to describe the building and to establish the engineering and economic alternatives.

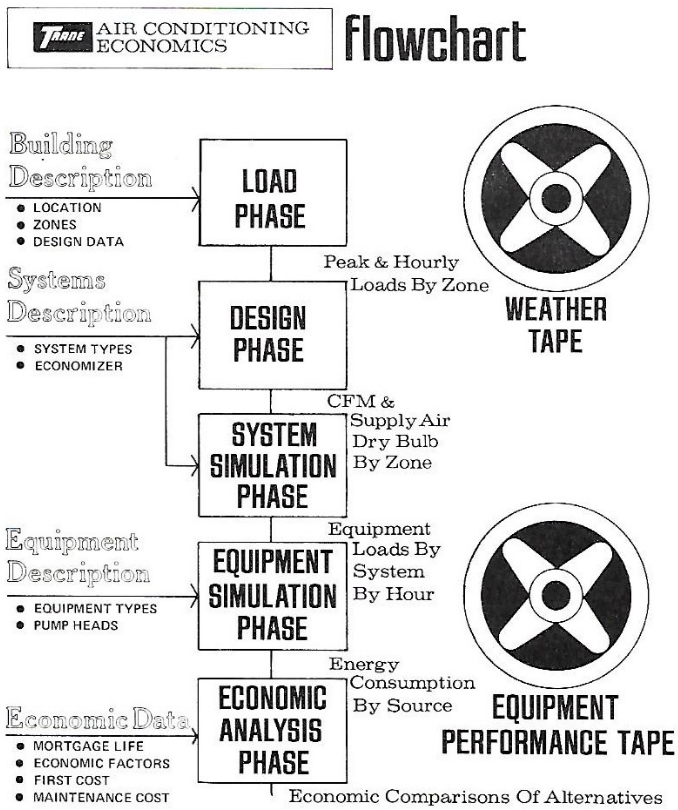


FIGURE 1

1973

instance, non-delivery of material required for this stage inevitably delays completion. As another example, two or more trades may be engaged, and it may be essential for one trade to finish its task before the others can continue.

A distinct, but allied, use of computers is the estimation of annual energy use. Since the computer time for a single calculation is short, it is entirely feasible for computations to be made for each hour (or any other interval) of a day, and to repeat this for as many days as one wishes. If actual meteorological data are supplied, the resulting print-out is an estimate of the energy which would have been used hour by hour and day by day in that particular period. Alternatively (and this is now preferred) a real or synthetic "reference" or "example" year can be used. The effects on the operation of systems of especially severe weather are easily computed. Example programs are BEEP (Electricity Council, UK), THERM (British Gas Corporation) and TRACE (Trane Company, USA).

For ordinary design-office use, the value of the computer calculation is not the saving of time (since an ordinary designer spends as little as 5% of his time on calculation) but the possibility of increased accuracy and of optimising the variables. Programs which merely use pre-existing tables, or adopt manual methods, do not provide higher accuracy. Those which are based on the fundamental equations of heat diffusion (e.g. by computing admittance or response factors) do give more accurate data, but at the expense of increased computer time.

Computer-aided design is most valuable in air conditioning, for the first cost of over-sized plant is high, and the energy cost of inefficient operation is also high.

The computer revolution is well illustrated by BSRIA Bibliography LB106 "Computers for building services", issued in 1978. It includes 311 abstracts of articles written in the 1970's, and lists some 133 programs then available.