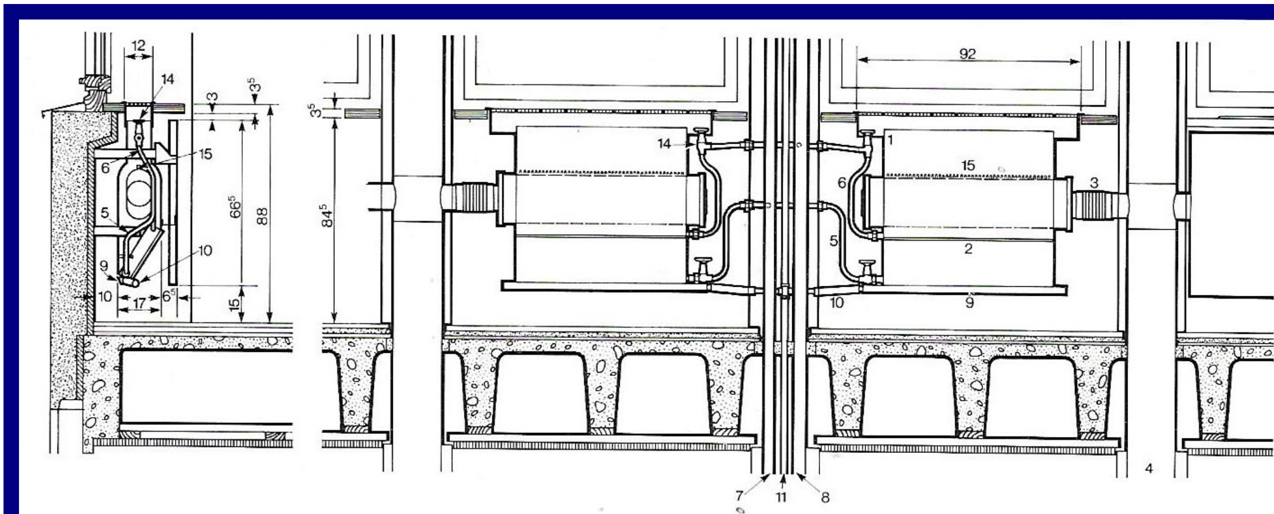

THE SPECIFIERS GUIDE TO AIR CONDITIONING

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BRIAN ROBERTS

C O N T E N T S

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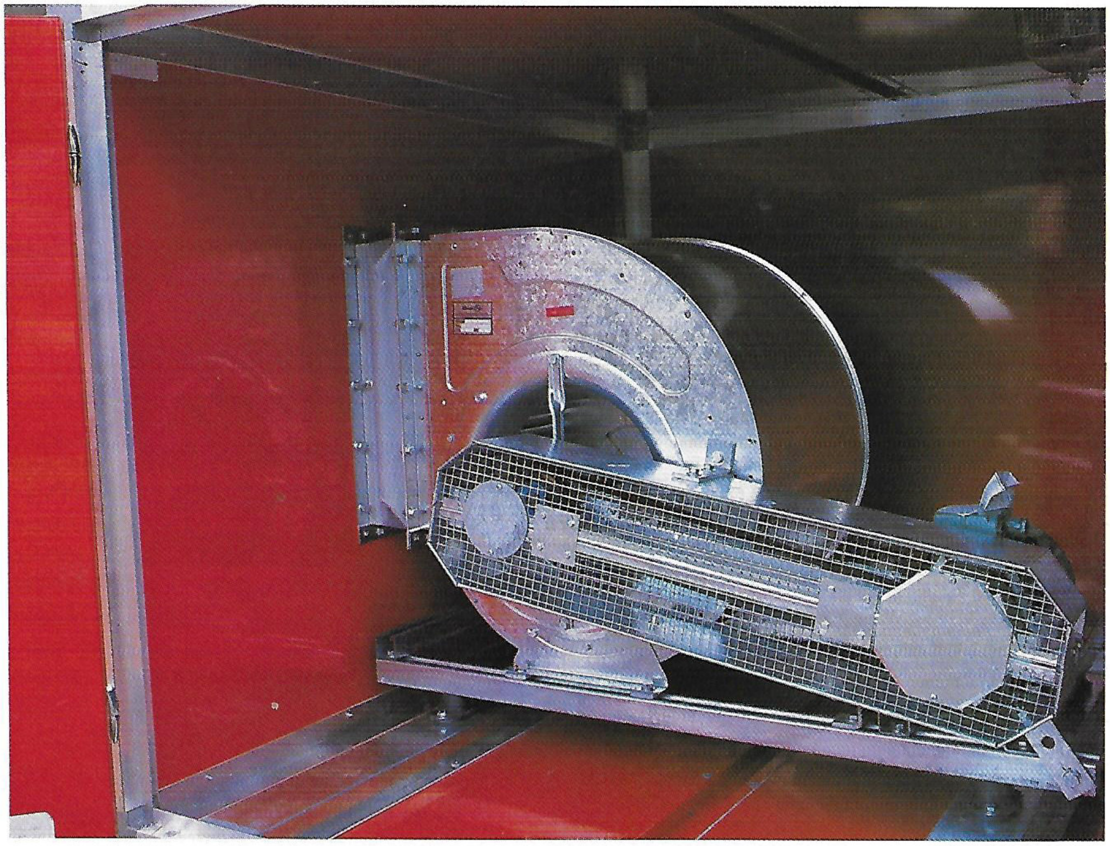
AIR CONDITIONING

RECIPE FOR SUCCESS



How is a good air conditioning installation created? What is the recipe for success? It needs good basic ingredients, mixed together in the proper proportions by the design team. The recipe put forward by A L Jaros Jun at the 1961 HEVAC International Conference in London is as true today as it was then:

(*a*) Those responsible for the hvac design should be considered a very important part of the building's design team.
(*b*) It should be a recognised part of their duties to advise about those features (in the building design) which will have an important effect on the initial and operating costs of the mechanical equipment – as well, of course, as on its proper and satisfactory functioning.
(*c*) Such advice will often require preliminary or comparative studies of alternative building schemes so that their work should start well before the building schematics are crystallised.
(*d*) In addition to this advisory function, they should work out and compare, different equipment and mechanical system schemes – as to their relative space requirements, results, investment cost, and cost (and ease) of maintenance.
(*e*) This second stage of studies should lead to further advice on building layout – shaft and machine-room locations and space requirements, etc., shafts and other spaces needed for duct and piping distribution, and the like.
(*f*) After there has been a complete meeting of the minds on all preliminary points, the preparation of contract plans and specifications must embody all decisions and accepted schemes, so clearly defined (and in sufficient detail), that there will be no ambiguity in the minds of estimators or contractors – and no difficulty in requiring them to provide the satisfactory plant which the engineer intended to design and obtain for the owner.
(*g*) All of which implies:
(1) The engineer must have adequate knowledge, ability and experience to suit the size, character and scope of the project.
(2) He must have the character and forcefulness to fight for the good of the project when necessary, even against his client.
(3) He must have the tact, logic and imagination to present cogent arguments in support of his recommendations – and to work out reasonable compromises with architectural and structural considerations, when needed for the over-all best interests of the project.
(4) During construction, he must co-operate with builders and subcontractors to secure a good job, but not accept short-cuts or compromises that will impair operating results, good maintenance, or proper life of plant.

All good stuff. Who could ask for anything more? But the punchline is yet to come!

> The engineer must insist on enough time and a sufficient fee to enable him to give his client all the service the project deserves. There is nothing more short-sighted than to spend a million or more on a plant that could have been thoroughly satisfactory if only two months more design time (or a few thousand more in fees) had been devoted to making it so.

This Supplement shows some of the ways of working towards achieving this "successful air conditioning installation".

HORSES FOR COURSES

A lot of time and effort is spent carrying out the detailed design of an air conditioning system, including the many variations and redesigns that crop up due to being "over budget" or through a rethink on the part of the client, architect or structural engineer.

Sometimes, these changes are doubly difficult, because the air conditioning designer never applied sufficient thinking power at the outset, to ensure that the right type of air conditioning system was chosen for the kind of application and particular project under consideration. How often is variable air volume or fancoil air conditioning specified simply because that is what the client had last time? How many air conditioning systems will never be satisfactory from the client or user viewpoints because they are stuck with the wrong system or equipment?

The problems may be all or some of the following:

□ unsatisfactory environmental conditions (temperature, humidity, ventilation rate, noise levels);
□ lack of individual control;
□ no flexibility to accommodate partitioning changes;
□ inability to operate a single floor or wing of the building;
□ high energy use and expensive to run;
□ difficult to adjust and maintain;
□ impossible to upgrade etc.

Now, no designer can take account of these things unless he can obtain a proper brief from the client. Neither can he do it if the cost and design restraints imposed by others prevent him However, if he can demonstrate to the client and professional team the range of system and design options, and the advantages and disavantages of each, before the final choice of system is made, he will at least have properly fulfilled his professional responsibilities. At the very least, at a later date he will have the dubious pleasure of saying "I told you so".

Convincing the client

In the UK, in the late 1950s and early 1960s, the problem was not so much in choosing the best of the competing air conditioning systems as in convincing the client that he ought to have air conditioning instead of a radiator system and opening windows.

The "client presentation" with coloured charts, "Radiators versus air conditioning", was almost standard practice for a time. Questions were posed, about how, or whether, the system could deal with draughts from open windows, traffic noise and fumes, summertime temperatures, and fresh air ventilation. Claims were made about improved worker efficiency, reduced absenteeism, higher occupant satisfaction and lower building redecoration costs.

Sometimes an attempt was made to rate these features on a points basis (marks out of 10).

It was not long before this type of presentation took on a more commercial aspect. The firm proposing the dual duct system had to try to convince the potential client that it was superior to the rival's induction system; and vice-versa.

It was soon realised that adding ,say, 7 out of 10 for "temperature control" to 6 out of 10 for "humidity control" did not make sense as they were not equally important in terms of environmental comfort. Therefore, all of the variables being considered and compared had to be "weighted" in some way. Thus, if temperature was weighted 9/10 in importance compared with 5/10 for humidity, the overall ratings became 7 × 9 ⅓ 63 for temperature, and $6 \times 5 = 30$ for humidity.

This method was developed by M J Wilson of the Carrier Corporation in the USA with articles in the magazines *Heating, Piping & Air Conditioning* (November 1958 and January 1965) and *Air Conditioning, Heating & Ventilating* (October and November 1960). It was subsequently developed by J B Olivieri in the *ASHRAE Journal* (January 1971) and featured as Chapter 1, "Principles for evaluation of air-conditioning systems" in the 1984 *ASHRAE Handbook, Systems Volume*.

Economic and quality evaluation

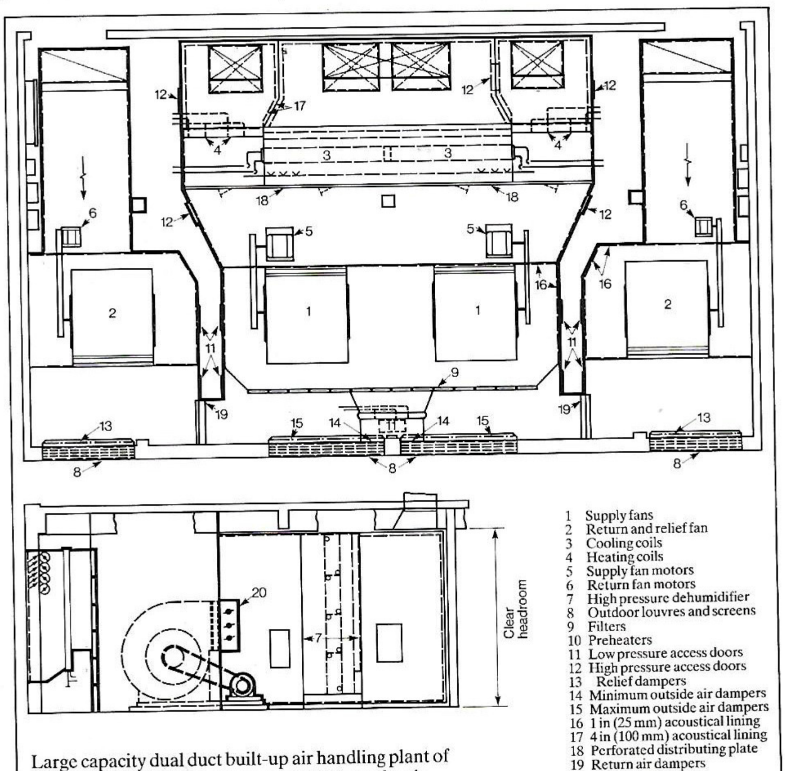
The general principle of one of the methods in use today requires the air conditioning designer to evaluate the various systems under consideration using a systematic method for comparing data relating to costs and quality.

This requires:

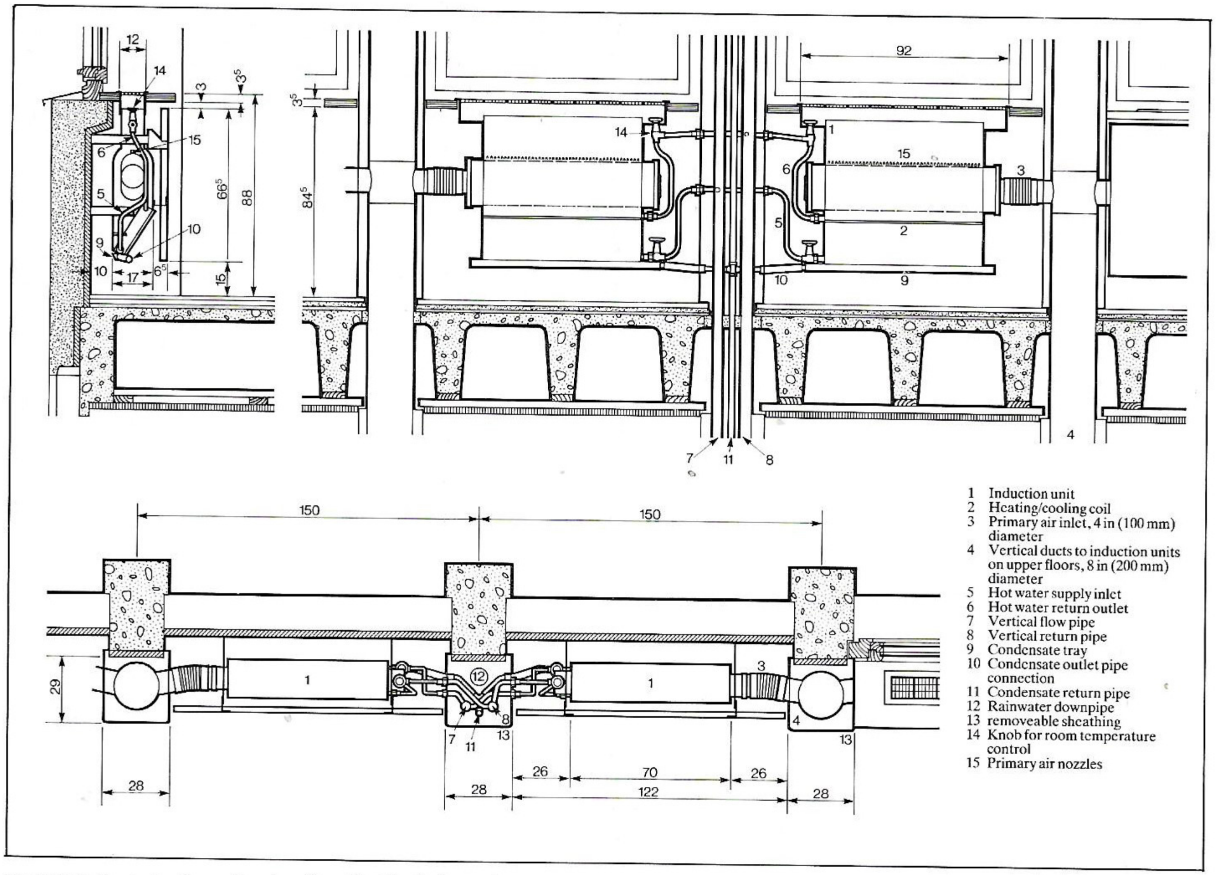
□ understanding the needs of the building owner;
□ being thoroughly familiar with the types of system and equipment being included in the evaluation;
□ being able to set out relevant information in a way that is both understandable and manageable;
□ Looking at objective, historic and subjective considerations.

The characteristics of an air conditioning system that can be measured objectively are usually financial, or their impact is related to costs. These features may include:

□ capital cost of the system;
□ capital cost of related services (eg



Large capacity dual duct built-up air handling plant of the early 1960s (USA), from a 1964 USA textbook.



Under-window induction unit system for office block air conditioning system, mid 1960s (Germany), from *Office buildings* by Joedicke Crosby Lockwood, 1962.

electrical servicess and plumbing);
☐ capital cost of related building features (eg plant space, structure, service shafts, casings for room units);
☐ operating costs (fuel, power, water, supervisory labour);
☐ maintenance costs (spares, consumables, labour).

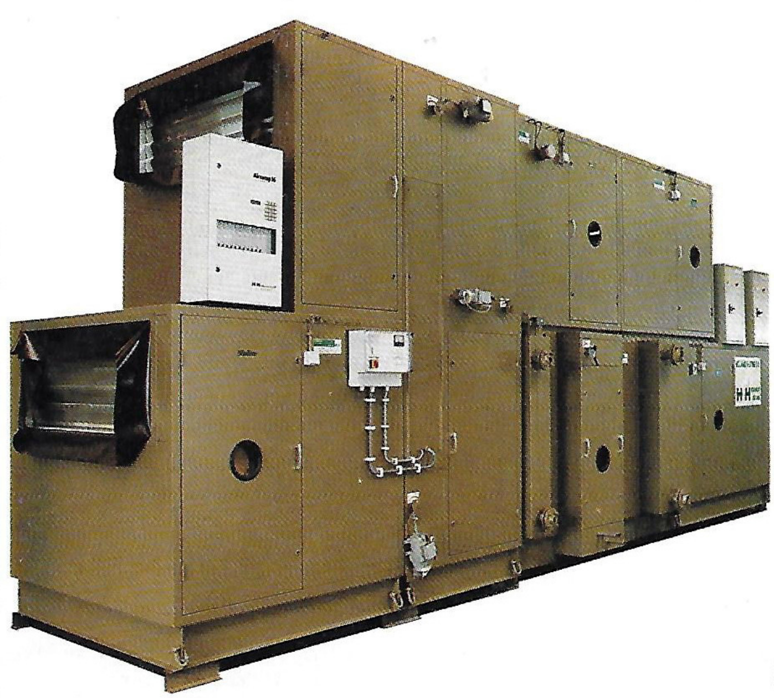
Some of this information may have to be computed or assessed from historic data, eg maintenance costs. Other historic data that may feature in the evaluation include equipment and component life expectancy, reliability and expected "downtime".

The most important characteristics from the designer's viewpoint are usually the subjective ones, ranging from comfort to appearance and flexibility.

An appraisal of comfort needs consideration of the following:
☐ space dry bulb temperature;
space relative humidity;
☐ air distribution (velocity and direction);
air quality (filtration, fresh air quantity,
☐ control of tobacco smoke and odours);
☐ noise level;
☐ quantity and quality of temperature control (size of controlled area and degree of adjustment attainable);
☐ and possibly mean radiant temperature.

Other subjective factors, together with objective and historic factors, may be in-

Custom built vav air handling unit with matched system of microprocessor controls and fan speed controllers. Photo: H H Airpower Ltd.



corporated in an Evaluation Worksheet as illustrated in Table 1. It may be necessary to produce a customised version of Table 1 for the particular project under consideration.

There is also a difficulty in weighing the importance of the economic factors against the quality factors. This decision making is ultimately a collaborative effort, involving the building owner or tenant and the whole of the professional team. Ideally, there should also be suitable input from the contractors, the major equipment manufacturers, and the eventual system operating and maintenance personnel.

System objectives evaluation

Another way of evaluating air conditioning systems is by establishing system objectives. The listed objectives may be individually classified as either mandatory ("musts") or desirable ("wants"). Competing systems are evaluated according to their ability to meet criteria determined by the needs of the building owner, the space and its occupants.

Objectives may include any or all of the usual cost or quality features, or may embrace a whole new range of "musts" and "wants".

Thus, in an office block, humidity control may be a "want" while in an art gallery it may be a "must". In a city centre development, concern over legionniares disease may rank "no wet cooling tower" as a "must".

Applications such as hospitals (bacteria control), prisons (vandalism protection) and television control rooms (no wet system or liquid leakage hazard) can all have their own special design objectives.

The "objectives evaluation" procedure would typically be as follows:

☐ List the objectives (concerns or characteristics);
☐ Identify as a "must" or a "want";
☐ Rank objectives in order of importance;
☐ List possible alternatives;
☐ Score on a points basis;
☐ Weight scores according to probability or seriousness of potential problem or its consequences;
☐ Make a choice.

Again, a collaborative or team effort is preferred.

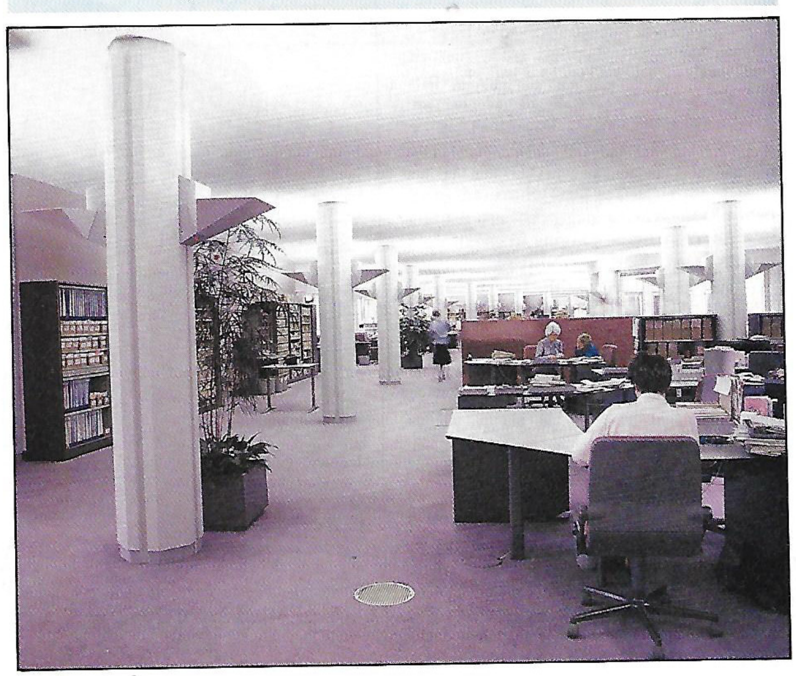
Whatever evaluation method is used the appraisal should be carried out in a systematic and rational manner by the whole of the design team.

It may be tedious. It may be time consuming. But in choosing the best air conditioning system for a particular client and project, inspiration will rarely be a satisfactory substitute for perspiration and effort.

TABLE 1: TYPICAL AIR CONDITIONING SYSTEMS EVALUATION WORKSHEET

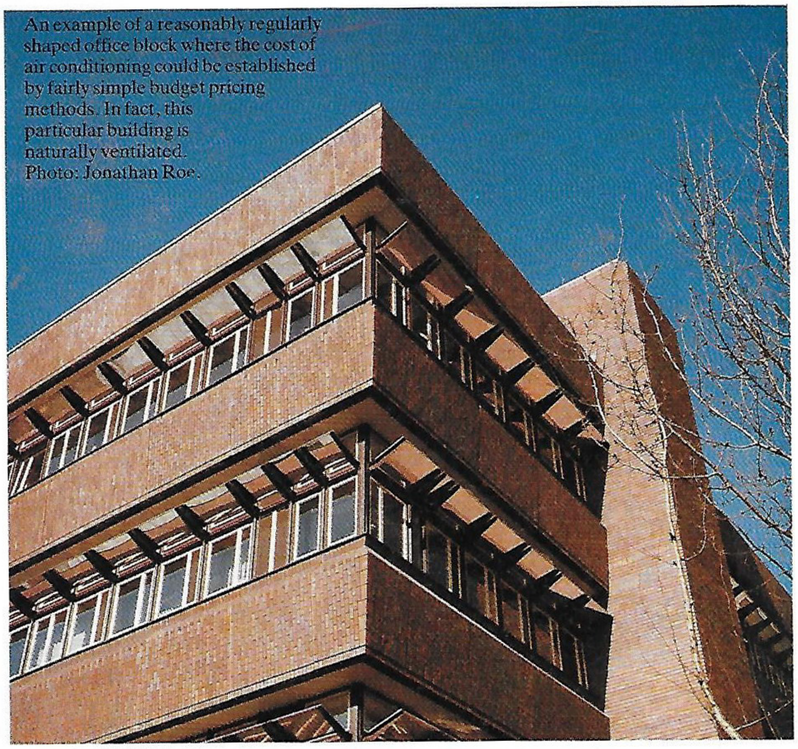
ITEM	SYSTEM 1			SYSTEM 2			SYSTEM 3		
	SC*	WTG	TOT	SC	WTG	TOT	SC	WTG	TOT
ECONOMIC									
INITIAL COSTS									
System	..	..	...	..	..	...	..	..	...
Related services	..	..	...	..	..	...	..	..	...
Related building	..	..	...	..	..	...	..	..	...
O & M COSTS									
Energy	..	..	...	..	..	...	..	..	...
Materials	..	..	...	..	..	...	..	..	...
Labour	..	..	...	..	..	...	..	..	...
TOTAL (ECONOMICS)			...			...			...
QUALITY (SUBJECTIVE)									
Appearance	..	..	...	..	..	...	..	..	...
Maintainability	..	..	...	..	..	...	..	..	...
Reliability	..	..	...	..	..	...	..	..	...
Flexibility	..	..	...	..	..	...	..	..	...
Comfort									
temperature	..	..	...	..	..	...	..	..	...
humidity	..	..	...	..	..	...	..	..	...
air distribution	..	..	...	..	..	...	..	..	...
air quality	..	..	...	..	..	...	..	..	...
noise	..	..	...	..	..	...	..	..	...
control	..	..	...	..	..	...	..	..	...
Fire/smoke control	..	..	...	..	..	...	..	..	...
Space suitability	..	..	...	..	..	...	..	..	...
Hazards									
pollution	..	..	...	..	..	...	..	..	...
liquid leakage	..	..	...	..	..	...	..	..	...
Public relations	..	..	...	..	..	...	..	..	...
Special (list)									
....	..	..	...	..	..	...	..	..	...
....	..	..	...	..	..	...	..	..	...
TOTALS (quality)			...			...			...

* SC = score (out of 10)
WTG = weighting or relative importance (on a scale of 0 to 10)
TOT = total weighted score (SC multiplied by WTG)

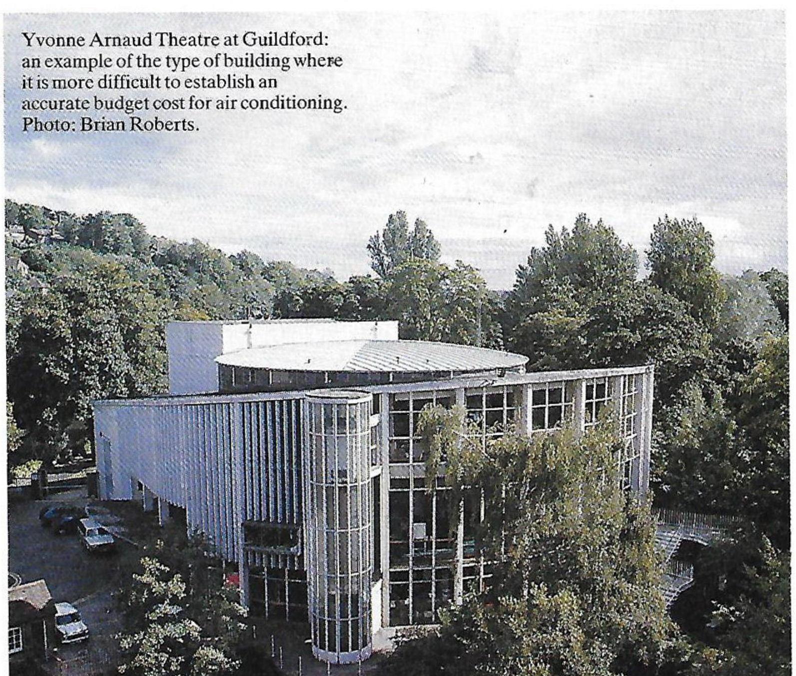


At the refuge Assurance headquarters in Cheshire the client's requirement for a high quality working and amenity environment which would accommodate changes in office technology, in an area of the country where a sealed envelope was not required, had a major influence on the installation chosen.

THE PRICE IS RIGHT



An example of a reasonably regularly shaped office block where the cost of air conditioning could be established by fairly simple budget pricing methods. In fact, this particular building is naturally ventilated. Photo: Jonathan Roe.



Yvonne Arnaud Theatre at Guildford: an example of the type of building where it is more difficult to establish an accurate budget cost for air conditioning. Photo: Brian Roberts.

Before the design of an air conditioning system begins, both the client and the rest of the professional team want the system designer to come up with a budget price. More likely, they want several prices – for different types or standards of system and for a range of building design options. This first budget is often very approximate and can only be established by reference to recorded data from previous projects. Accordingly, this first *order of cost* estimate may only be accurate to within about 25%.

Once the basic design decisions have been made and the team begins to develop the design of the building and its services, a better estimate of the probable value of the air conditioning content will be required. This is often a *final sketch design* estimate and the aim is to improve the accuracy to, say, within 15%.

Obviously, these cost estimates may affect the design – particularly when it looks as if there may be a budget overrun. Then it's either back to the client or back to the drawing board. Once such questions are sorted out the design process continues. As the detailed design is completed and the tender drawings and specifications are drawn up, there is a need for one last evaluation of the cost of the air conditioning scheme. This is the *detail design* estimate and is an attempt to ascertain the likely amount of the best tender figure to be submitted, to within about +5%; ie hopefully, the tender sum will be at least 5% less than the budget allowed. This last estimate has to try to take account of the market conditions likely to be prevailing at the time the project is sent out to tender, typically a "no win" situation.

Background

Budget estimating procedures within the air conditioning industry as a whole have traditionally relied upon *unit cost* data, derived from historic analyses of actual projects. Perhaps the most common indicator for expressing the cost of air conditioning is in £/m^2 of conditioned floor area.

This sounds fine until one attempts to find out what is included in this figure for a particular building. Does it include the boiler plant? Does it include or exclude the domestic hot water part of the boiler plant? Which of the following are included or excluded from the air conditioning price: toilet ventilation, kitchen ventilation, garage ventilation, ventilation of lift-motor rooms and plant rooms? Are the costs of the associated electrical starters, switchgear and cabling included? And what about the integrated air/light fixtures or the room fan-coil unit casings? How does one compare the cost of a system with pneumatic controls (price for piping and air compressor included) with that for a system having electric controls (price for wiring excluded)? It's not easy, but detailed records built up on a consistent basis are the first step.

The £/m^2 method has been found to be of reasonable value for office blocks but often very difficult to apply in other applications. In these circumstances, alternative cost indicators expressed as £/unit of installed capacity (eg £/kW of refrigeration, or £ per m^3/s of supply air volume flowrate) may be more realistic. However, to be able to use these alternative indicators one needs to be able to estimate either the cooling load or the air conditioning supply air volume. (Some insight on outline design data is given in the article "Checks and Balances" in this Supplement.)

In general, the unit cost method has been found to be an acceptable method for establishing a first order of cost budget estimate. It requires little time or resource, always provided that adequate records are available from which to extract the basic data. There are a number of situations where this approach has been found wanting. These are where:

☐ there are a number of air conditioning options for any given type of building;

☐ there are wide variations in material, labour and subcontract elements for plant of the same capacity, depending on the selection and arrangement of central plant, distibution services and room equipment;

☐ progressive estimates of cost, which improve in accuracy, are required as design detail is developed.

Various other budget costing methods are available and are compared in Table 1. These values are a guide. With practice, and by acquiring a good databank of information, times can be reduced and levels of accuracy improved.

Classification

To develop these procedures it is necessary to devise a method of classification for air conditioning systems, for subsystems and for components.

One possible classification for *categories of system* and for *types of system* is given in Table 2.

It is also necessary to be able to classify *subsystems* and *components*. One suggested arrangement is given in Table 4.

When comparing cost data from different projects it is essential to identify the type of air conditioning system and to determine what subsystem items or components are included in the analyses. In particular, costs under *special items* may heavily weight the cost of a given design.

Budget cost estimating

The majority of pricing methods will build up a store of recorded costs for a particular type of building and a given type of air conditioning system. More sophisticated records will hold price data on subsystems or components, broken down in elements

TABLE 1: AIR CONDITIONING BUDGET COST ESTIMATING METHODS

Method	Typical time to produce (hours)	Probable accuracy (± %)	Order of difficulty
SYSTEM-BUILDING RATE	1	20 – 25	4 simplest
SYSTEM-BUILDING LOAD RATIO	2	15 – 20	3
SUBSYSTEM	3	10 – 15	2
COMPONENT	4	5 – 10	1 most difficult

TABLE 2: CATEGORIES AND TYPES OF AIR CONDITIONING

	CATEGORY		TYPE
1·0	ALL-AIR	1·1	Low velocity (conventional)
		1·2	Low velocity with terminal reheat
		1·3	Low velocity with local air handlers
		1·4	High velocity single duct constant volume
		1·5	High velocity single duct variable volume
			1·5·1 VAV only
			1·5·2 VAV + perimeter heating
		1·6	High velocity dual duct
2·0	AIR-WATER	2·1	2-pipe induction
		2·2	4-pipe induction
		2·3	2-pipe fan coil + primary air
		2·4	4-pipe fan coil + primary air
		2·5	Chilled radiant ceiling + primary air
3·0	ALL-WATER	3·1	2-pipe fan coil + outside air through wall
		3·2	4-pipe fan coil + outside air through wall
4·0	MULTIPLE UNIT or UNITARY	4·1	Self-contained room air conditioners
		4·2	Self-contained room heat pumps
		4·3	Packaged terminal air conditioners
			4·3·1 Air-cooled
			4·3·2 Water-cooled
		4·	Packaged terminal heat pumps
			4·4·1 Air-cooled
			4·4·2 Water-loop type

TABLE 3: CHARACTERISTICS OF STANDARD BUILDING

Characteristic	Data
USE	Offices
SIZE	77 m long, 15 m wide, 34 m high
SHAPE	Rectangular
LOCATION	London
ORIENTATION	Long sides North/South
NUMBER FLOORS	10 office floors
GROSS AREA	13000 m^2: 350 m^2 roof 11550 m^2 offices/circulation 110 m^2 basement
NET CONDITIONED AREA	10000 m^2 total: 1000 m^2/floor
CONSTRUCTION	Long walls: 50% double glazing End wall: solid
SOLAR PROTECTION	Clear glass Internal blinds south face
MODULE SIZE	6·5 × 2·2 m
AREA	14·3 m^2
NUMBER	700 total: 70 per floor

TABLE 4: CLASSIFICATION OF AIR CONDITIONING SUBSYSTEMS AND COMPONENTS

	SUBSYTEM	COMPONENT
1·0	CENTRAL PLANT	Refrigeration Cooling towers Air handling 7 units Boilers Pumps Controls Starters Electric cabling Air compressor
2·0	DISTRIBUTION	Ducting Duct insulation Piping Pipe insulation
3·0	ROOM EQUIPMENT	Outlets Terminal units Individual controls
4·0	SPECIAL ITEMS	Allied space heating Water treatment Fire/smoke detection & control Building management systems Special acoustic treatment Heat recovery devices

TABLE 5: CHARACTERISTICS OF STANDARD AIR CONDITIONING SYSTEM

Characteristic	Data
CATEGORY	Air-water
TYPE	4-pipe fan coil + primary air
EQUIPMENT DUTIES	
Refrigeration	13330 kW (133 W/m^2)
Heating	1800 kW
Primary air	14 m^3/s (2 plants at 7 m^3/s
Fan coil units	Number: 700 (70 per floor)
PLANT ARRANGEMENT	
Chillers with air cooled condensers	2 × 50% duty (roof)
Air handling units	2 × 50% duty (roof)
Boilers (gas)	2 × 66% duty (roof)

TABLE 6: AIR CONDITIONING BUDGET COST WORKSHEET SYSTEM-BUILDING RATE METHOD

	Project name: Location: System		Date: Engineer:
	VARIABLE	INPUT DATA	FACTOR
1·	Building size m^2	A = ...	Z = ...
2·	Building shape (sketch)		S = ...
3·	Building height (No floors)	N = ...	H = ...
4·	System category (define)	....	K = ...
5·	Standard area cost rate		CR = £....
6·	Cost index adjustment to (date)	....	I = ...
7·	Other adjustments (state)	....	J = ...
8·	BUDGET RATE PRICE BR = Z×S×H×K×CR×I×J	=	£/m^2
9·	BUDGET TOTAL PRICE BT = BR × A (area) m^2	= £............	

similar to those shown in Table 4. The problem is always how to use the recorded data and make suitable adjustments for the building and system (and commercial circumstances) under consideration.

One concept which has been used for office block air conditioning is that of a *standard building* equipped with a *standard air conditioning system*, to which the design loads, features and costs of the system being considered are in some way related. This approach requires that the standard building and system should be reasonably representative of current trends and costings. Ideally, the "standard" should be a recently completed building where the design and cost information are real; also the building should be of reasonable size so that the £/m^2 or similar figures are not distorted by small scale effects.

The data for a standard building could be typically as in Table 3. The standard air conditioning system as installed in the standard building could be along the lines detailed in Table 5. The most essential item of information is the cost of this standard air conditioning system. This is conveniently expressed as a *standard area cost rate*, called *CR*, in £/m^2.

System/building rate method

This is the simplest of the costing methods available and is suitable for the first, or order of cost, estimate. It uses a *budget worksheet* as in Table 6 and a series of adjustment factors: building size *Z*; building shape *S*; building height *H*; and system category *K*. These are applied to the *CR* value and multiplied by the conditioned area, *A*, of the building under consideration. The base *CR* value, computed at a given date, may be uplifted to the predicted tender or final account date by a cost index, *I*, and modified according to other factors which are significant, according to the judgement of the designer or estimator, by a further factor *J*.

These methods produce a *budget rate* price, *BR* (£/m^2) and a *budget total* price, *BT* (£).

The adjustment factors may be held in tabular form, or the whole procedure may be computerised. The following figures are based on data from real projects, collected over a number of years. Data in other records may suggest different values for some of the factors, but the overall trends are expected to be substantially similar.

System/building load ratio method

This method is similar to the preceding one. It uses the following factors: building size *Z*; cost ratio *C* (derived from a load ratio *L*); building height *H*; and system category *K* (or, preferably, system type *T*).

It also uses, as before: *I, J, CR, A* and *N* to derive *BR* and *BT*; but the procedure differs as follows:

Building area $A = (A_e + A_i)$

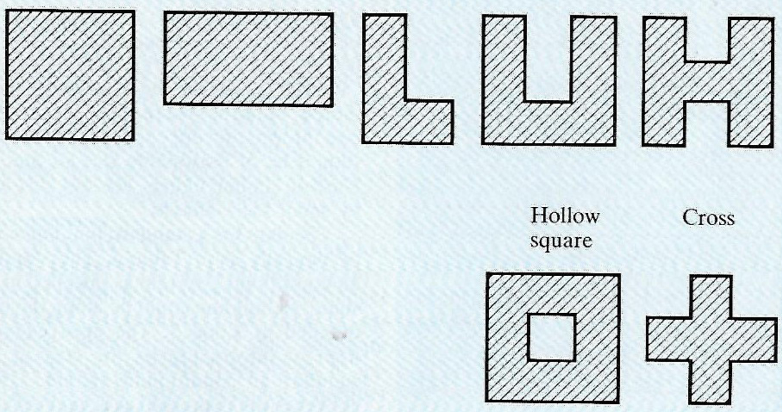
where e and i refer to external and internal zones.

TABLE 7: BUILDING SIZE ADJUSTMENT FACTOR Z

Conditioned area A ($m^2 \times 1000$)											
<1	1	2	4	6	8	10	12	15	20	30	>30
1·35	1·30	1·24	1·16	1·08	1·03	1·00	0·99	0·97	0·96	0·95	0·92

TABLE 8: BUILDING SHAPE ADJUSTMENT FACTOR S

Square Rectagular "L" "U" "H"



0·96	1·00	1·08	1·21	1·24

TABLE 9: BUILDING HEIGHT ADJUSTMENT FACTOR H

Number of floors								
<5	6	8	10	15	20	25	30	>30
0·92	0·94	0·96	1·00	1·02	1·04	1·06	1·08	1·10

TABLE 10: SYSTEM CATEGORY ADJUSTMENT FACTOR K

System category ALL-AIR	AIR-WATER	ALL-WATER	MULTIPLE UNIT or UNITARY
1·21	1·00	0·92	0·87

TABLE 11: AIR CONDITIONING BUDGET COST WORKSHEET SYSTEM-BUILDING LOAD RATIO METHOD

Project name:		Date:
Location:		Engineer:
Systems:		
VARIABLE	INPUT DATA	FACTOR
1. Building size m^2	A = ...	Z = ...
External zone Ye = ...	Ae = ...	
Internal zone Yi = ...	Ai = ...	
2. Cost ratio	% glass = ...	C = ...
	Load ratio L = ...	
3. Building height (no. floors)	N = ...	H = ...
4. Standard area cost rate		CR = £....
5. Cost indent adjustment (date)	....	I = ...
6. Other adjustments (state)	....	J = ...
7. System adjustment	Ext zone	Int zone
Category	Ke = ...	Ki = ...
OR		
Type	Te = ...	Ti = ...

8. BUDGET RATE PRICE
Ext one BRe = Z × C × H × CR × I × J × Ke(Te) = .../m^2
Int one BRi = Z × C × H × CR × I × J × Ki(Ti) = .../m^2
9. BUDGET TOTAL PRICE
Ext zone BTe = BRe × Ae = ...
Int zone BTi = BRi × Ai = ...
Total for building BT = (BTe + BTi) = ...

Expressed in ratio form

$Y_e = A_e/A$ and $Y_i = A_i/A$

or

$Y_e + Y_i = 1{\cdot}0$.

From tables, the *load ratio, L*, of the building under consideration may be determined according to the percentage glass in the external façade and values of Y_e and Y_i, relative to the standard building (ie 50% glass, $Y_e = 1{\cdot}0$, $Y_i = 0$). (This approach replaces the *shape factor, S*.) From another table, the *cost ratio* factor *C* may be established according to the value of *L*. This table recognises that doubling the system capacity does not double the cost. In fact, as shown in studies carried out by the American petrochemical industry, the cost/load ratio follows roughly the 0·6 power rule.

A worksheet for this method is given in Table 11. It has the advantage that different categories or types of system may be used for external and internal zones. The procedure may be used for either the order of cost or the final sketch plan estimate.

A more accurate variation of this method computes the *load rate*, or *LR* value, in W/m^2 for external and internal zones, and uses this in place of the load ratio. The method may be extended to cope with applications other than office blocks.

Subsystem method

This procedure is more advanced. It is suitable for the final sketch design estimate and, in some circumstances, the detail design estimate. It all depends on the amount of information available and level of accuracy aimed for.

Essentially the method breaks the system down into four subsystem elements, each with its own cost factors and adjustment factors, namely: central plant; distribution system; room equipment; and special items.

The central plant cost is adjusted according to the quality and standby arrangements of the main items of equipment. Distribution systems are assessed according their complexity and length. Room equipment costs are calculated according to the size of module served and the number of room outlets or terminals and the degree of individual room control provided. Any special items may be added into the overall budget.

Component method

This is the most complicated of the budget pricing procedures, and the most accurate, and is intended to establish costs at the detail design stage. The component method is similar to the subsystems approach, but goes into considerably more detail – rather like a simplified bill of quantities. Each of the component elements (as Table 4) is adjusted by factors to take account of the number, type and arrangement of components and the length/complexity of the distribution services in the installation under consideration.

CHECKS AND BALANCES

At the early planning stages of building and air conditioning design it is essential for the air conditioning designer to be able to figure out almost instantaneously. the effects of all the different building options on the cooling load, air distribution sizing, space requirements, electrical loads (and costs).

In this situation, his only weapons are his brain and his briefcase. His ammunition is either the historic analyses of past projects, or his ability to establish some quick loadings by simplified calculation techniques. These checks are an aid to decision making – to balance one possible solution against a range of options.

Past and current projects may be analysed to build up a record system or computer database of relevant technical information. Building data may include building type/use, gross and net (conditioned) area, and details on location, number of floors and shape (with sketch), orientation, construction (particularly percentage and type of glazing in external facade and solar protection provided), details on position/size of plant rooms and service shafts.

Air conditioning data may consist of system type, building cooling and heating loads, supply air volumes, environmental conditions (and control limits), details of internal loads, information on degree of individual control available, summary of equipment electrical loads and any special or unusual features.

Typical check cooling load figures are given in Table 1. Approximate air volume flow rates, which may be used as a cross-check of preliminary cooling loads and as an aid to initial duct layout and sizing, choice of air handling units and sizing plant rooms, are given in Table 2.

Preliminary estimates of the installed electrical power loadings of air condition ing plant and auxiliaries also need to be established, using data as in Table 3. Where more design information, such as kW of cooling and air flow rate, is available, reference to Table 4 permits a breakdown of the probable electrical loads of the various blocks of air conditioning plant. Short cut calculation methods may be developed to establish building loads or other basic design data with an improvement in accuracy over the tabular methods shown above. Office blocks, in particular, are well suited to this approach and are featured in the following examples. Table 5 illustrates a typical split-up of the main components of the air conditioning load for office blocks with increasing amounts of glass in the external facade.

In a typical office building, some 65-75% of the cooling load is attributable to solar gains and internal loads, while fresh air may account for a further 15%. These constitute the bulk of the load.

It is more effective when establishing initial indications of the total cooling load

TABLE 1: CHECK AIR CONDITIONING COOLING LOAD FIGURES FOR UK

BUILDING TYPE		W/m² OF CONDITIONED FLOOR AREA
OFFICES		
External zones	20% glass	97
	30% glass	106
	40% glass	114
	50% glass	120
	60% glass	126
	70% glass	133
	80% glass	142
Internal zones		85
Conference/board rooms		150 – 190
Computer rooms		200 – 350
HOTELS		
Bedrooms (per room)	Double	2·8 kW
	Single	1·8 kW
Public rooms		120-200
Restaurants		about 0·7 kW per person
Cocktail bars		150-190
MOTELS		75-95
DEPARTMENT STORES		
Basement and ground floors		130-150
Upper floors		90-130
SHOPS		150
BANKS		130-175
FLATS AND APARTMENTS		75-95
THEATRES/ AUDITORIA		0·20 kW per seat
SUPERMARKETS		95 – 135
INDUSTRIAL BUILDINGS		
Single storey, lightweight, flat or pitched roof, small glass areas		95 plus equipment and machinery loads

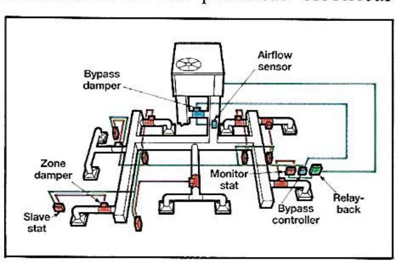
TABLE 2: CHECK AIR CONDITIONING AIR VOLUMES FOR UK

SYSTEM OR BUILDING TYPE	SUPPLY AIR VOLUME FLOW RATE (m^3/s per 100 m^2 floor area)
ALL-AIR SYSTEMS	
High & low velocity	
VAV, single and dual duct	
OFFICE BUILDINGS	
External zones	0·5-0·9
Internal zones	0·4-0·5
Computer rooms	1·0-2·25
HOTELS	
Bedrooms	0·4-0·6
Public rooms	0·8-1·3
RESTAURANTS	1·3-1·8
SHOPS, STORES	0·8-1·2
BANKS	1·0
THEATRES	0·01 m^3/s per person
AIR-WATER SYSTEMS	PRIMARY (FRESH) AIR
Room fan-coil or induction	
OFFICES	0·13-0·2
HOTEL BEDROOMS	
Double rooms	0·035-0·06 m^3/s per room
Single rooms	0·02-0·035 m^3/s per room

TABLE 3: CHECK AIR CONDITIONING MOTOR POWERS FOR UK

SYSTEM	MOTOR POWER* (W/m² of conditioned floor area)
ALL-AIR: high velocity; vav, dual duct, single duct	35-55
ALL-AIR: low velocity	28-46
AIR-WATER: high velocity; induction	27-48
AIR-WATER: low velocity; room fan-coil	30-50

* Includes supply and return/exhaust fans, refrigeration, chilled water pumps, air-cooled condenser fans or cooling tower fans and condenser water pumps. Fan-coil values include for room units. Excludes standby motors, electric air heaters and ventilation systems, eg toilets, kitchens, garages, lift or equipment rooms.



A single zone constant volume unit is now able to provide both variable air volume and variable air temperature: Carrier VVT system.

TABLE 4: CHECK AIR CONDITIONING MOTOR POWERS FOR UK

SYSTEM OR EQUIPMENT	MOTOR POWER (kW) Per m^3/s air flow	Per kW refrigeration
AIR CONDITIONING		
ALL-AIR: high velocity; vav dual duct, single duct		
Supply air fans	1·6-2·8	0·08-0·15
Return air fans	0·8-1·6	0·04-0·08
ALL-AIR: low velocity		
Supply air fans	0·5-1·2	0·03-0·06
Return air fans	0·2-0·8	0·01-0·04
AIR-WATER: high velocity; induction		
Primary supply air fans	1·6-3·0	0·01-0·02
Exhaust air fans	0·4-0·8	0·003-0·006
AIR-WATER: Low velocity, Room fan-coil		
Primary supply air fans	0·4-0·8	0·005-0·008
Exhaust air fans	0·3-0·7	0·002-0·005
Room fan coil units Duty 0·25 m^3/s	150 W	
Duty 0·50 m^3/s	200 W	
REFRIGERATION		
Direct-expansion/chilled water		
Compressor		0·3-0·35
Chilled water pumps		0·025-0·04
Zone water pumps		
Induction/fan-coil		0·03-0·06
Air cooled condenser fans		0·025-0·03
Cooling tower		
Fans		0·012-0·018
Pumps		0·03-0·05
HUMIDIFIERS		
Electrode steam type	14 per m^3/s of fresh air	

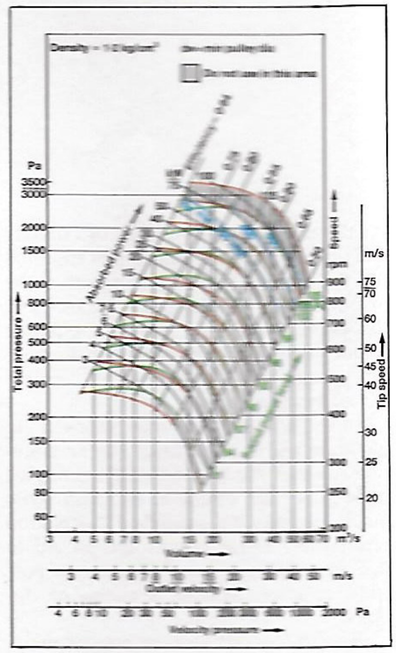
TABLE 5: COMPARATIVE ANALYSIS OFFICE BLOCK COOLING LOAD (UK TYPICAL)

Glazing/wall ratio	25%	50%	75%
Solar gains	35	48	57
People, lights, equipment	30	24	20
Conduction	5	4	3
Ventilation (fresh air)	20	15	12
Plant gains	10	9	8
TOTAL	100	100	100

TABLE 6: SAMPLE CALCULATION SHEET FOR ESTABLISHING PRELIMINARY AIR CONDITIONING COOLING LOAD, UK OFFICE BLOCK

ITEM	FACTOR	LOAD (W)
EXTERNAL GAINS PER FLOOR		
Solar plus conduction		
E Wall (........%.... glass)	.... m* × .... W/m length =	....
S Wall (............% glass)	.... m* × .... W/m =	....
W Wall (............% glass)	.... m* × .... W/m =	....
N Wall (............% glass)	.... m* × .... W/m =	....
INTERNAL GAINS PER FLOOR		
People (m^2/person= ....) = ... W/m^2		
Lights .... W/m^2		
Power .... W/m^2		
TOTAL .... W/m^2	× .... m^2 net area =	....
VENTILATION GAINS PER FLOOR		
People (number =........)	× .... W/person =	....
	FLOOR SUBTOTAL	....
	× .... (number of floors)	
	= BUILDING TOTAL	....
Add ROOF GAIN	.... m^2 × .... W/m^2	....
	= NET TOTAL LOAD	....
Add PLANT GAIN	.... % (for system type ....)	....
	GROSS TOTAL LOAD =	

* Linear length of wall.



Typical performance of a backward curved fan including absorbed power curves: Kiloheat.

(or trying to reduce it) to concentrate on those items which are the most significant:

Solar gain typically forms the major part of the cooling load. Ways of reducing these gains by changes elsewhere can be particularly cost-effective and include: less glass area, heat absorbing or reflective glasses, use of solar blinds and screens, use of window overhangs/reveals, change of window orientation.

Internal gains from people, lights and equipment are next in terms of significance and being, in the main, directly proportional to floor area, can be determined with a high degree of accuracy.

Conduction gains, through walls, roof and glass, can involve complicated calculations – not necessary at this early stage as they rarely amount to more than 5%.

On the other hand, *plant gains* are sometimes overlooked with unfortunate consequences for they can represent as much as 10% of the total load.

These preliminary loadings can be established by simple graphs and tables or by computer programs. One method uses a standard form, as in Table 6, in which data are entered in the form of W of cooling required per metre length of external wall according to orientation and design of external facade (ie % glass, type and shading devices); this accounts for both solar and conduction loads. Internal loads are entered according to combinations of occupation density/lighting loading/small power-equipment loads. Loads due to fresh air can be similarly read from tables, according to occupancy or floor area; plant gains can be assessed in percentage terms according to type of system.

FLAVOUR OF THE MONTH

Are there trends and fashions in air conditioning? Have some good types of system and equipment been discarded unnecessarily? Are some of the design concepts now being introduced old ideas dressed up in new clothes? Are the manufacturers responsible for deciding which systems and equipment are the "flavour of the month"?

It is probably not unfair to say that the answer to all of these questions is a qualified "yes", which means that you can't pin it all on the manufacturers! After all, there are forces outside the industry which exert their own particular form of influence – be they governmental, social, economic, or related to energy, health or environmental concerns.

Refrigeration for air conditioning

Although the term "air conditioning" is believed to have been coined in 1906, air cooling systems allied to mechanical ventilation predate this by some 20 years. These early systems used ice blocks, well water, cold water in pipes or as sprays, and brine coils for cooling.

Early applications, making use of melting ice in the airstream, include: Berlin Hygiene exhibition (1887), Carnegie Hall (1891), Broadway theatre (1892), the Houses of Parliament (1893) and Robinson and Cleaver's department store (1903).

Later, with the development of water-chilling equipment, ice-storage gave way to systems incorporating chilled water storage or buffer tanks – to increase peak capacity, prevent short-cycling of compressors, avoid control problems and, sometimes, utilise low-cost off-peak electricity. With improvements in the design of chillers and controls, and pressures on space and costs, it became accepted practice in the UK from the 1960s onwards to avoid the use of chilled water storage.

The 1970s energy crisis saw the introduction of a variety of 3-pipe and 4-pipe heat recovery systems with double-bundle (and even triple-bundle) condensers and the reintroduction of large water storage vessels (including the use of fire sprinkler tanks) as heat sources or sinks. Now, a number of enterprising manufacturers in the USA have rediscovered the ice-storage system with "ice harvesting equipment for thermal energy storage systems", "static, glycol-based ice builders" and the like. A clear case of the manufacturers setting the trend!

Whatever happened to the absorption water chiller? Carre took out a French patent back in 1859. Various machines were developed and in use up until about 1915 when ammonia reciprocating compressors with electric motors largely took over. The Carrier Corporation introduced a lithium bromide machine in 1945; this type of machine was further developed by Carrier and Trane in the 1950s, being particularly suited to large scale applications where steam or mthw is available, eg hospitals and factories. Early operational problems, such as crystallisation of the solution, were overcome and improvements in steam consumption were realised by the introduction of the double-effect machine in Japan in 1965. A number of UK installations, upwards of 10 000 kW of cooling, were made in the 1970s.

Small (up to about 80 kW) direct-fired machines, using gas, were also in use, and a 10 kW solar-powered absorption unit by Arkla was commercially available in the USA. All seem to have disappeared. Or, somewhere out there, are they still alive and well?

After the Second World War, the UK saw the development of first the industrial and process air conditioning market, followed by the growth of the commercial or comfort industry, from the 1960s up to the present day. Industrial installations used reciprocating compressor systems, usually direct-expansion type, with cooling towers or sometimes evaporative condensers.

Small installations were air-cooled. Most installations, especially the larger ones, used open compressors: hermetic and semi-hermetic units were generally used in the smaller sizes. As larger buildings were constructed the cooling requirements increased. Duplex compressor water chillers were used up to about 400 kW: for larger duties, the centrifugal water chiller was introduced. But fashions change.

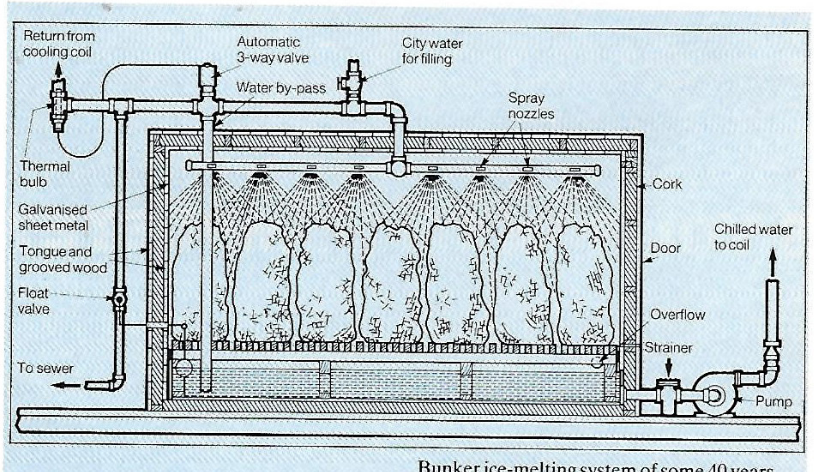
The last 10 years have seen the development of large air-cooled chillers and a preference for multiple (same-size) reciprocating compressors, providing standby, reduced starting currents, ease of part-load operation and spares standardisation. And when did you last see a belt-driven compressor? Again, did the manufacturers forsee the market, or did they create it?

This general preference for air-cooled equipment, and current concerns over wet cooling towers and legionnaires' disease, may signal the death-knell for water-cooled refrigeration using cooling towers in city centre developments; in spite of the technical and commercial advantages which can be raised in its favour.

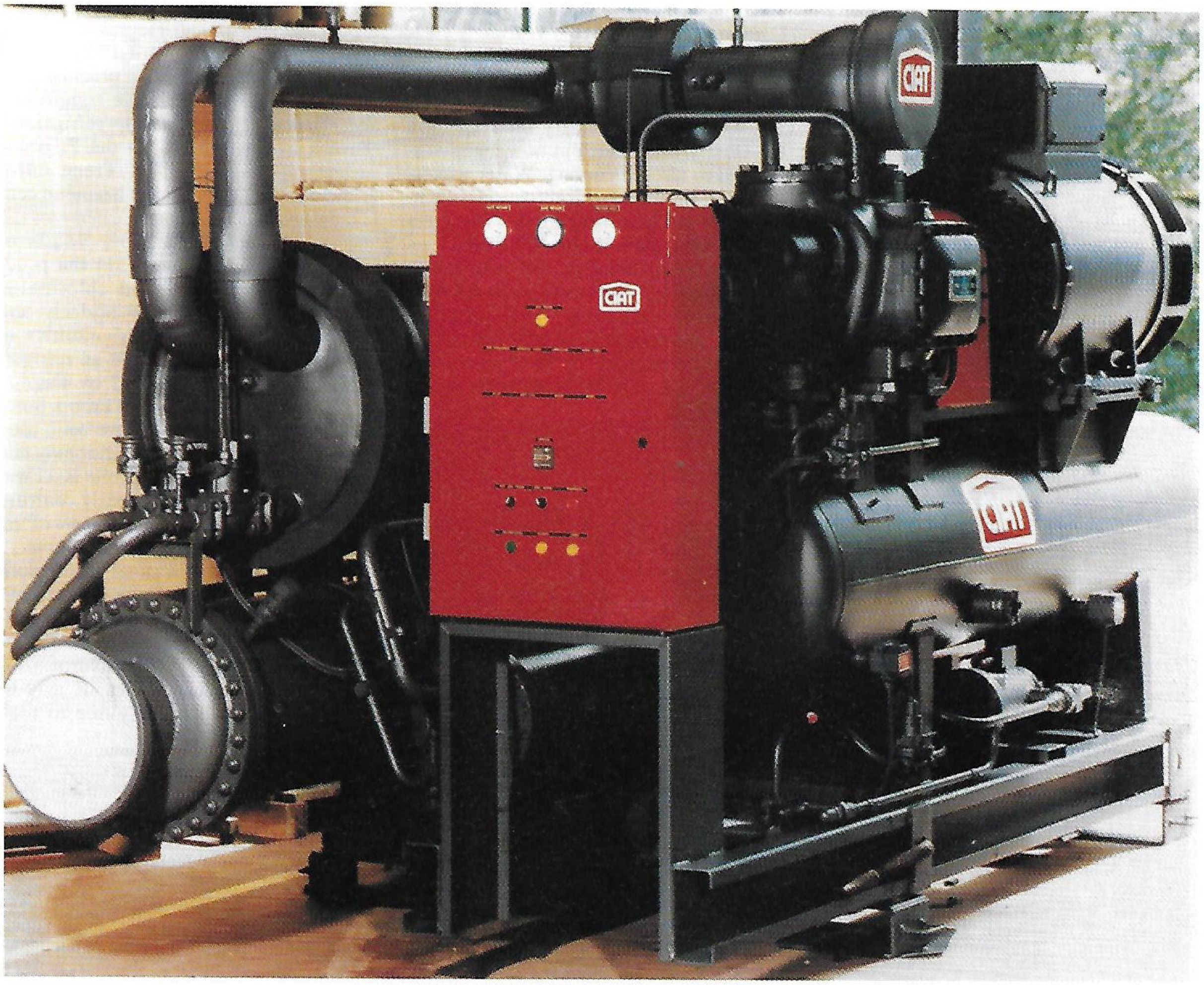
The screw blower dates from 1878; the screw compressor from Sweden and Lysholm's patent of 1934. A big improvement was the oil-injected version of around 1950, which no doubt led to its introduction for refrigeration purposes by Stal-Laval in the early 1960s, and later by Grasso.

Astute marketing in the 1970s, combined with its suitability for generating condenser water temperatures above 40°C in the heat reclaim era, saw a significant number of installations by Dunham-Bush in the USA and the UK. The screw machine was further developed by Hitachi; there are also machines by Frick (York), a new APV Hallscrew, a Mark II Stal-Mini, and a Carrier Screw on the way. Does this mean a new wave of popularity? Will it put a dent in the reciprocating compressor market?

Pioneers in the development of the rotary, or rolling-piston compressor, were the USA and Germany in the 1920s. Frigidaire and GEC developed small



Bunker ice-melting system of some 40 years ago, American style, providing chilled water for air conditioning, from a drawing in an old Trane manual.



Water chiller of the screw compressor type: Ciat (UK) Ltd.

machines, while in the 1930s Vilter tried to foster this type of compressor for larger machines. A number of US manufacturers used small rotary compressors for air conditioning in the 1960s. Now, near the end of the 1980s, improved versions of the rotary compressor are being introduced. The scroll compressor has also appeared from Hitachi and Trane, and soon from Carrier. It will be interesting to see how widespread their adoption becomes.

Air conditioning systems

Mixing of cold outside air with warm furnace air, for temperature control, can be traced back to Richard T Crane (founder of the Crane Co) in 1868. But early air conditioning systems were what we would now call the conventional, low-velocity all-air type. However, double-duct systems are mentioned in Sturtevant catalogues of the 1890s and by Roger Preston in 1909: they re-emerged in the 1950s in high velocity form, with the development of suitable high-pressure mixing boxes by companies such as Anemostat, Buensod-Stacey, Connor Corporation.

While giving excellent temperature control with good control of ventilation, air distribution and average humidity levels, they were space and energy inefficient and relatively expensive. They have been supplanted by vav systems, which some may argue are technically inferior, but which are considerably cheaper! (However, difficulties with providing winter heating have persuaded vav box manufacturers to offer twin plenum units handling hot and cold air separately – the dual conduit system of 20 or more years ago).

Carrier introduced the 2-pipe induction or conduit system in 1939 and took out further patents in 1950. The Swedish Velovent system was introduced in 1956, the Swiss Jetair in 1956, and the Italian Hi-Jet around 1960. All saw considerable use in multi-room, multi-storey buildings – particularly high-rise offices, in the USA, the UK and in continental Europe from around 1955 to 1970. Where are they now?

The earliest fan-coil systems were commercially developed in the USA in the late 1920s. However, it is only in the last five years or so that they seem to have been taken seriously in the UK, with 4-pipe systems proving a serious competitor to vav. Again a battle of the manufacturers.

Other systems and equipment that seem to have come and gone include: ventilating ceilings; chilled radiant panel ceilings; air washers and water spray humidifiers (thanks to humidifier fever and legionnaires' disease); water-loop room heat pumps; electrostatic precipitators, automatic viscous air filters, and the majority of integrated air-light systems: while the market place never seems to have taken to heat-pipes and only to rotary heat wheels in a limited way. All have been "flavour of the month" in their time. On the other hand, packaged air handling units (rather than built-up plant) and electrode-steam humidifiers appear to be permanent fixtures, while prefabricated plantrooms, incorporating air handling/refrigeration/control packages, are gaining in popularity.

Refrigerants

Ice, snow and chemical mixtures were the earliest cooling agents. Vapour compression refrigeration relies upon the liquefaction of a gas and its subsequent evaporation, the first example of this being for SO_2 in 1780. (In fact, Jonathan Swift in *Gulliver's Travels*, written in 1726, makes an astonishing reference to liquefaction and separation of gases).

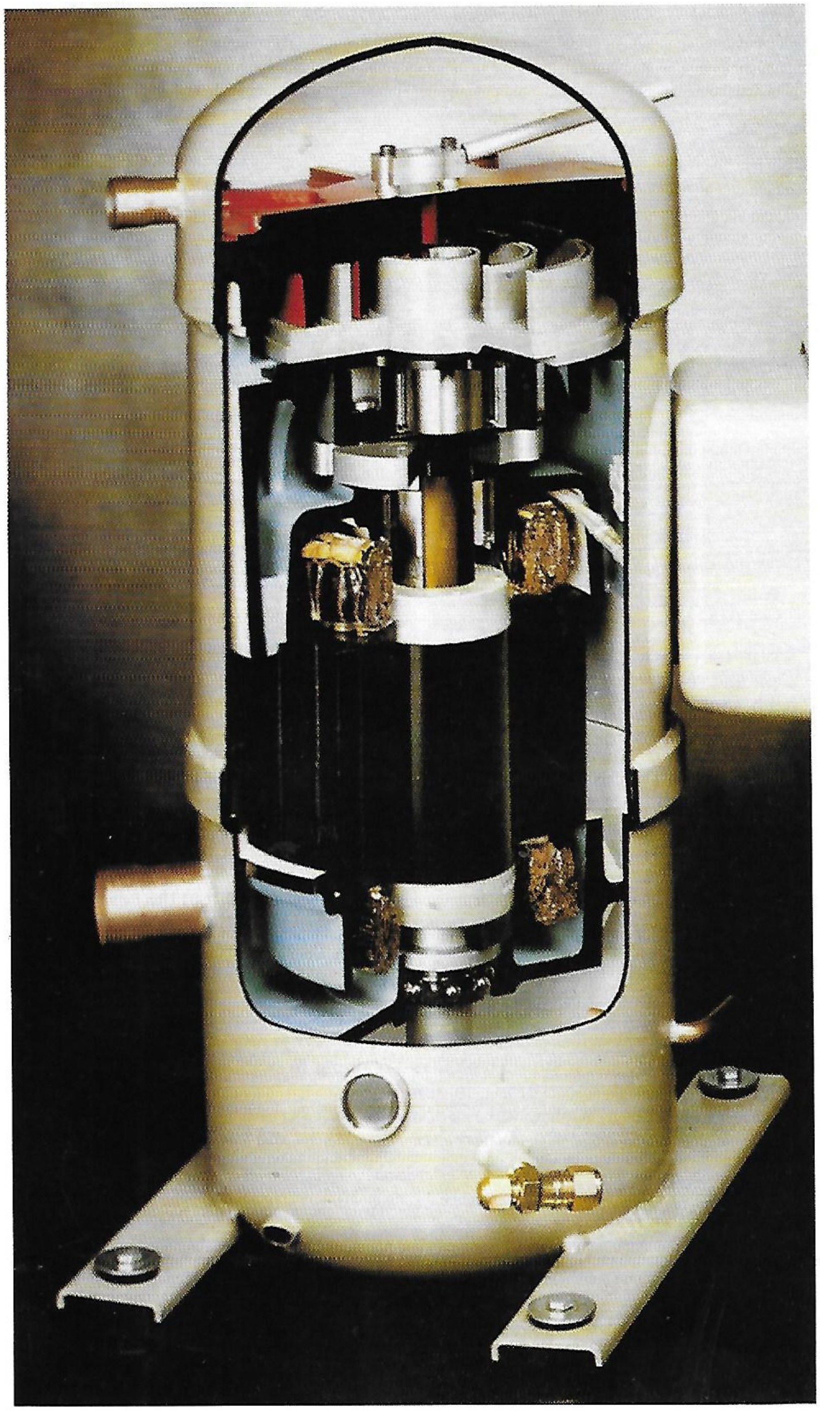
In the *Young steam engineer's guide* (Philadelphia, 1805), Oliver Evans described how a cooling machine based on the evaporation of ether could work. In 1834, Jacob Perkins obtained a British patent for just such a machine with a hand-operated compressor and a water-cooled condenser. Over the next 30 years or so, practical machines were developed by Twining in the USA, by James Harrison in Australia (who recognised the potential for the export of frozen meat), by Tellier in France and Linde in Germany. All faced difficulties with constructing compressors and finding a suitable refrigerant. Professor Linde and, independently, David Boyle in the USA, built practical machines in 1872/73 using ammonia as the refrigerant. In spite of its high toxicity, ammonia was widely used, particularly in large industrial applications, for the next 70 years.

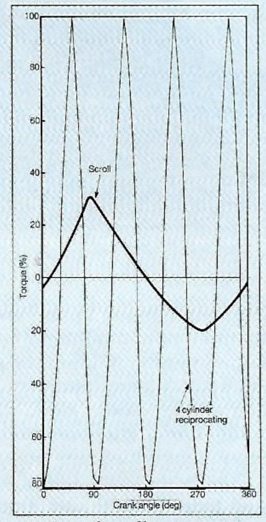
Other refrigerants used during this period included SO_2, CO_2 and methyl chloride. Air was also one of the earliest refrigerants, being widely used up until the First World War, but now mainly restricted to aircraft cooling. Water vapour also found limited application, as in steam-jet refrigeration, fitted in the liners *Queen Mary* and *Queen Elizabeth*.

The development of the centrifugal, or turbo-compressor, required a refrigerant of high molecular weight and low vapour pressure if a small number of stages and a reasonable speed were to be achieved. About 1910, Leblanc in France, used first water-vapour and then carbon tetrachloride in experimental machines. But it was not until 1922 that Carrier was able to demonstrate the first practical centrifugal, employing a 4-stage compressor and dichloroethylene as the refrigerant. (Brown Boveri introduced the Frigibloc turbocompressor in 1930: Trane introduced the first direct-drive hermetic centrifugal in 1938).

Between 1893 and 1907, Swarts of Ghent published his work on the production of fluorinated and chlorinated hydrocarbons. In 1929/30 Midgely and others in the Frigidaire laboratories in Ohio recognised their value as refrigerants. These were marketed by Dupont in 1931 under the trade name Freon. Since that time, R-12 and R-22 have been used in many thousands of air conditioning and refrigerating applications, while R-11 was adopted by Carrier for his early centrifugal machines. Now a wide range of refrigerants of this family are available.

However, there is a cloud on the horizon: or perhaps one should say there's a hole in the ozone layer! And the experts tell us that it is largely down to these fluorinated and chlorinated hydrocarbon refrigerants, now called cfcs. It may be that the problem is mainly due to their use as aerosol propellants but the banning of cfcs, in aerosols or air conditioning or anywhere, looks imminent (though R-22 appears to be a "protected species", at least for the moment).





Cut-away view of scroll compressor. Chart illustrates the low torque variation which occurs in a scroll compressor compared with a reciprocating compressor. Source: Trane.

There will no doubt be a frantic search for suitable economic alternatives. It seems certain that health and safety considerations will never permit the use of ammonia and their like again. Air and water-vapour are safe refrigerants but neither practical nor economic with present equipment. It may be that much of the machinery will have to change. We are in the hands of governments, the scientists, the environmentalists and 0— inevitably, the manufacturers.

EVERYTHINGS UNDER CONTROL

Todays' automatic controls for air conditioning can perform almost any function and provide extremely high levels of response and accuracy. However, where the controls system leads the air conditioning cannot necessarily follow.

It is vital, therefore, that the air conditioning and its controls be considered from the earliest planning stages. Decisions on building size, shape, height, orientation, form of construction, relationship of adjacent buildings, size of building module, choice of heating and cooling mediums – all these things affect the control system design and the effectiveness (or otherwise) of its eventual operation.

Most air conditioning engineers will be unable to work out the fine detail of the control systems design. The putting together of the "building blocks" or hardware and interconnections of a particular manufacturer's range of equipment is almost inevitably a job for a specialist. But the danger arises in assuming that the controls specialist is able to deduce what the intended function and performance of a particular air conditioning system is intended to be, from either the designer's or the client's viewpoint. As a result many systems and their controls are incompatible. Frequently,the controls are "over-engineered" and capable of too many or too complicated cycles or levels of accuracy to which the system is incapable of responding. The control engineer's reply, often quite justifiably, is that the system is "under-engineered" and suitable neither for the application nor for the design intent!

One starting point is to establish why air conditioning is required, what it is supposed to do, when it is supposed to do it, and how it responds when the unexpected happens.

Air conditioning may be required for the comfort, or the health or welfare, of the occupants of a building; for the efficiency or effectiveness of a manufacturing process; or to maintain the quality and life of a stored product. Often it has to cater for more than one of these options.

The air conditioning will almost certainly be required to control space dry bulb temperature, probably within + 2°C for comfort; maybe + 0·5°C for process work. Laboratory or process applications may require wet bulb or dew point temperature control. Relative humidity may be controlled over quite a wide range in comfort work; for example, 55% maximum with no lower limit (ie the system has no humidifying capability), perhaps + 10 or 5% in some comfort/process applications, or even + 2% in special cases. Other variables to be controlled may include the following: ventilation rate, carbon dioxide concentration, air volume, air velocity, air direction/motion, static pressure in a duct or in a space (either in absolute terms or relative to another pressure), surface temperature and so on. Control is also required over a wide range of variables in associated fluid distribution systems like heating hot water, chilled water, condenser cooling water or air, and refrigerant.

The system designer and the control engineer must, together, analyse and agree:

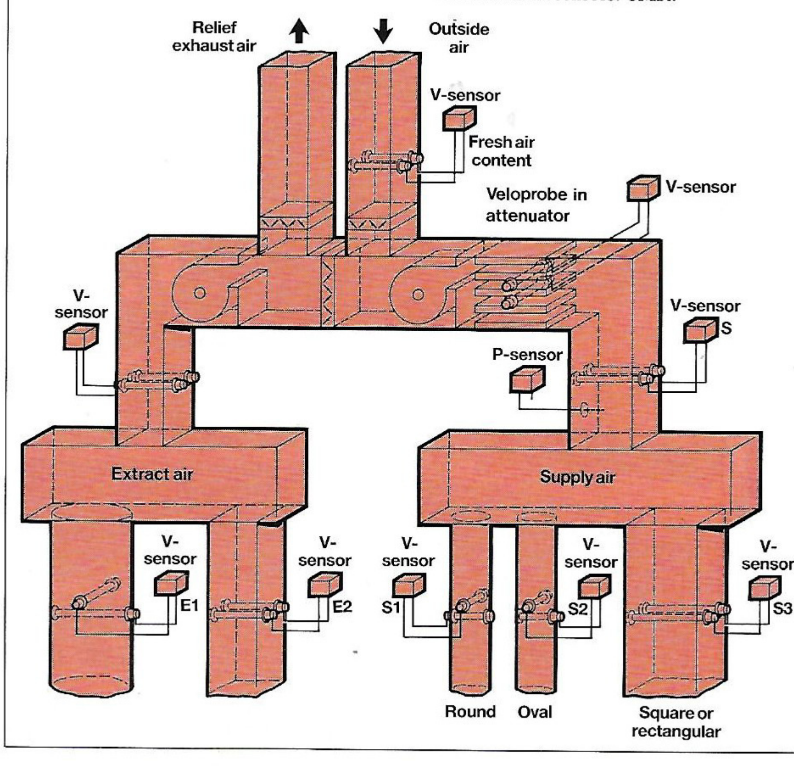
☐ control functions – variables to be controlled and the acceptable limits;

☐ safety limits – maximimum or minimum conditions of temperature, humidity, pressure etc;

☐ operating functions – sequence of plant starting and stopping according to use, load conditions, energy conservation

Stainless steel duct averaging velocity measuring tubes: CMR.

VAV air conditioning system: application of low pressure and air flow measurement sensors: CMR.



or emergency situations.
They must look at system behaviour: peak loads, partial loads, average load conditions, pattern of variation, sensible/latent heat balance (particularly at part-load), load diversity, hours of system operation, system response related to thermal capacity and effects of the building, system lags, control system response and lags, permissible tolerances and the time the system can be "off-limits".

They must consider control and operational requirements: supervision, monitoring, records, type of adjustment and regulation, summer/winter changeover, day/night and weekend operation, start-up and close-down procedures, on-line maintenance, duty/standby working, high/low limit protection, frost protection, electrical protection, electrical safety and so on.

It is essential to pose questions like:
☐ What is the size of the controlled space? (Generally the smaller the better, but the more it costs, and is the system capable?)
☐ Are the systems zoned and how?
☐ What is the minimum load and how does the heating/cooling/ air distribution system cope at this level? (Indeed, can it?)
☐ What happens to the system in the event of failure of the electricity supply?
☐ What happens when the supply is restored? (For example, refrigeration machines and electric heaters should be recycled to the zero-load position before restarting or re-energisation.)
☐ What happens in the event of a fire?
☐ How do life-safety and smoke control systems or procedures operate?
☐ Are the sequence interlocks and safety controls still in place when the operator switches from automatic to manual control?
☐ Are they in place when the operator switches back to automatic? (There was a building in Houston where the operator took the no 1 large centrifugal chiller off-line for service. As he put it back no 2 machine came in automatically. The current inrush of both machines starting simultaneously severely damaged the electrical distribution system and put the building's cooling out of action.)

The control system will be more effective if the following pointers to air conditioning design are borne in mind:
(1) A system with constant air volume and variable air temperature is generally superior to one with variable air volume.
(2) There must be an effective system of distributing the conditioning air within the spaces served, eg no draughts or short-circuiting.
(3) Heating and cooled coils must be properly sized and piped in counterflow.
(4) To control relative humidity below an upper limit there should be a source of reheat, either by return air (not mixed air) bypass or a reheat coil.
(5) Refrigeration must be available in multiple units or increments of capacity to meet part and minimum load requirements without short-cycling, if necessary by provision of chilled water or ice storage.
(6) System components must be arranged in the proper order to permit the control required, eg reheat downstream of dehumidifying coils, humidifiers downstream from a source of heat.
(7) System components and ductwork must be arranged so that controllers can be located to measure truly representative conditions.
(8) Components and ductwork should be arranged to minimise air stratification, particularly at mixing boxes and discharge plenums.
(9) The building and system should be divided into areas of like-load requirements to permit separate control of each area.
(10) Control valves and dampers must be properly sized and selected. (In particular, the pressure drop across the device must be large enough to provide proper flow control).
(11) Space controllers must be sited where they measure a condition representative of the whole space – a return duct is often the most suitable – and where readings are not distorted by draughts, solar radiation or abnormal heat conduction (as on an outside wall).
(12) The supply pressure (and possibly temperature also) for which control valves and dampers are sized must be maintained at the level necessary to achieve rated output or match load conditions. (At part-load chilled water must be at a low enough temperature to achieve the dehumidification required.)
(13) **Comparable and compatible equipment should be used, both for the air conditioning system and for the automatci controls.**

The simplest air conditioning plant and the simplest control system are often the best, and will be the easiest to maintain, adjust and keep in operation. It is wise to avoid unnecessarily complicating the system, or providing special sequences or operating cycles when these are not essential.

Building energy and management system: Transmitton.

C & T WITHOUT SYMPATHY

Commissioning and testing (c&t) of air conditioning installations has always been a problem. It has never attracted much sympathy from the client, the tenant, the main contractor or the professional team. Many problems arise as a result of their decisions (or lack of them) with the buck finally being passed to the commissioning engineers.

The difficulties associated with commissioning of air conditioning systems in the UK were recognised in a 1956 IHVE paper by William Ramsay. Then, in the 1960s, when the growth of commercial air conditioning came about, the continuing lack of knowledge on the subject prompted the then IHVE to develop a series of *Commissioning Codes*, the first of which was on *Air distribution systems, high and low velocity* published in 1971. Other IHVE *Codes* and BSRIA *Guides* followed. Many large contractors set up commissioning departments, most of which are now disbanded, and the work handled by outside specialist commissioning firms: a retrograde step?

Why, after all this time and the outpourings of technical expertise, are there still so many problems with the commissioning of air conditioning systems? Some problems are technical and often related to flaws in the basic design (making designers responsible for commissioning their own systems is a great cure for this!). Unfortunately, most of the problems are organisational, commercial, political or self-made.

Careful checks of the air conditioning ductwork are an important precommissioning activity, from a Drake & Scull brochure.

What the client expects and should know

The client wants to have his building constructed to specification, to be completed on time and within budget and with the air conditioning functioning correctly. When some, or all, of these expectations are not fulfilled, the contractor is usually blamed – often unjustly. The client has a right to expect value for money, but equally he is not entitled to something for nothing.

Commissioning can be extremely complex. It requires adequate resources to be allocated to it – in terms of time, money and manpower. When tender prices are squeezed and building programmes shortened (often by the client) it is usually the commissioning which finishes up being skimped. Since commissioning is not billed by "quantities" it is often looked upon as an area where time and money can be saved. The client should be aware of the risks he is taking on-board by making unreasonable demands for savings in these areas (after all, he or his unfortunate tenant will be the one that ultimately suffers). It is equally important that the client should be made to realise that continual pressures upon the designers and the installers to save money, by cheapening systems and equipment, eventually lead to the very items necessary to achieve proper commissioning (and future successful operation and maintenance) being deleted. In extreme circumstances it is possible for systems to be designed and installed which are just not capable of being properly commissioned and regulated.

Typical problems

Commissioning of the air conditioning lies somewhere near the end of the critical path. As the project completion date approaches it becomes the focal point for all of the design and installation delays which have occurred up to that moment (or which are about to occur). It goes without saying that these delays may have been nothing to do with the air conditioning. More often than not, they relate to lack of information, failure to make decisions or give approvals on-time, changes of instruction, bad weather (it does sometimes snow in winter), strikes, shortages of men or materials, poor planning, bad management and so on; the guilty parties have been the client, the professional team, the main contractor, a manufacturer or supplier, or some other party not directly involved in the project. The air conditioning contractor may not be blameless, but his major sin is often not having been sufficiently outspoken in explaining his problems or making his needs known (and having capitulated too easily when the threat of placing the next order elsewhere just happened to be mentioned to his chairman).

However, by the time commissioning of the air conditioning comes around it becomes a very convenient scapegoat for all these earlier problems and failures – and it assumes an unwelcome but important role in the commercial/contractual/legal battle when claims and blame are being dished out, when cost penalties are being invoked and variations and extras being argued about. By this time, the architects and consultants have handed out all the information and drawings they intend to hand out (whether adequate or not), the builder has his cranes off-site and the scaffolding down (never mind those high level diffusers) and the finishing trades are moving through the building – locking the doors behind them to stop the entry of commissioning engineers.

The client is trying to move his furniture and staff in (ahead of schedule); the local authority and fire inspectors (having had the plans for two years) have just discovered a breach of some unspecified regulation which means rebuilding half the first floor; the air conditioning contractor has been told to move his huts off the site, just when he needs them most. He is still waiting for the plumbing contractor to put the water on and for the electrical contractor to give him a permanent electrical supply so he can "run up the fans" (which the main contractor wants for drying out the building – because he's finishing the glazing next week). And to make matters worse the air conditioning contractor has just discovered that he's spent all the money in his estimate. To be successful at commissioning in these circumstances is surely something of a triumph!

The role of the professional team

Since the professional team is "first into bat" the decisions it makes regarding the design of the building and its services have significant impact of the success, or otherwise, of the commissioning of the air conditioning. It seems this is not always fully realised at the time!

This "design" is almost inevitably a compromise. There must be give and take between the requirements of the architect, the structural engineer and the services engineers, and within the framework imposed by the client, the statutory authorities, the quantity surveyor's cost control, the time available, the site itself – and hopefully the practicalities of the construction and the setting-to-work of the services. The success of the final building, its air conditioning and the satisfaction of the client depend upon this collaboration between all of the parties involved.

How the builder can help

The builder, or management contractor, should be more prepared to understand the problems of the air conditioning contractor, otherwise they will later become his problems also.

Buildings are made up of static components but when the air conditioning is started up it becomes a dynamic thing as air, water, refrigerant and electricity flow through their distribution networks. It is at this point that tension usually starts to mount as the commissioning process can take a lot of time and effort without, to the unitiated, any visible progress being made. It must be appreciated that the arrangement of the air conditioning is not necessarily immediately related to the form or layout of the building. While the building can be completed and handed over floor by floor, the ducting and piping systems are frequently distributed vertically and cannot be commissioned in piecemeal fashion.

So the commissioning must be properly planned. The builder should insist that the air conditioning contractor produces a comprehensive programme covering the sequence and timing of all commissioning activities, and identifying the necessary manpower, skills, and dependent trades/facilities.

Now comes the difficult part. The builder must be prepared to modify his preconceived construction programme to incorporate these requirements. Those parts of the building which house the main parts of the air conditioning central plant or distribution are usually relatively simple from the builder's viewpoint and may be allocated a low priority or "late start". Providing late access or squeezing this part of the programme (and subsequently delaying it in practice) is one of the prime causes of installation overrun and inadequate commissioning. The other requirement, not treated seriously, is for an essentially sealed building. This means doors and windows complete (and shut), partitions erected, suspended ceilings and luminaires in place. When this is not the case, the commissioning is inevitably poor and problems come to light after building occupation.

What the contractor should do

He must adopt a more professional approach to the commissioning of the systems that he installs. He must provide the technical and management skills to carry out commissioning and be prepared to pay for outside expertise when necessary or appropriate. He must make available the necessary commissioning instruments and record forms, and plan and monitor all the tasks that precede commissioning – including the work of others. He must collect together all of the technical data required for commissioning (and here the designer has a vital role which he often fails to fulfil). There should be a draft of the *Operating & Maintenance Manuals* available and the final commissioning figures should be incorporated into them.

Back in 1977, CIBSE held a symposium "Testing and commissioning of building services installations". A lot of air has flowed through the ducting since then. Undoubtedly things have improved but there is still considerable scope to do better. It is probably time for another symposium to bring things up to date!

□ BSRIA seminar, see page 37.

Determining the air volume flow rates in a hospital air conditioning system using a flow measuring hood, from a Drake & Scull brochure.