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Contents

Special features

News feature

Departments

Front cover: The environmental-engineering services of Blackweir Ambulance Station, Cardiff, have been upgraded recently (photo: Phoenix Burners Ltd.)

Hospital Engineering

Vol 29
October 1975

Refuse disposal policy in the NHS

by J. McDOWELL,
M.I.H.V.E., F.I.Hosp.E., C.Eng., M.I.Mech.E.

After the recent local Government reorganisation in Britain, the responsibilities on domestic refuse are broadly divided to make district councils responsible for refuse collection and county councils responsible for refuse disposal. Industrial wastes are usually disposed of by private contractors.
The major portion of the National Health Service's (NHS) refuse can be classified, if properly segregated, as domestic and hence handled by local-authority services. However, the remaining portion approximately one-third poses a problem for the NHS.

NHS refuse problem and some solutions

The refuse collection and disposal problem that the NHS is responsible for is conventionally solved by refuse being placed in plastics or paper sacks at the various departmental sources, conveyed by porters to the bag-storage area of an incinerator plant and burned.

The sterile products remaining represent approximately 10% by volume and 30-40% by weight of that collected, and are suitable to be handled as domestic refuse by the local-authority collection and disposal services.

However, cost alone demands that all of the alternative methods for refuse disposal should be considered before a solution is provided to any particular area, site or building.

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Some solutions to the NHS refuse disposal problem are:

- incineration
- controlled tipping (by a local authority, the NHS or a private contractor)
- maceration and a wet disposal system

Clearly any consideration of alternative solutions must have regard to current legislation, projected changes in legislation and guidance on good practice. A resumé of this information is given in Appendix A.

The tendency towards a higher plastics content (p.v.c. being a particularly difficult constituent to deal with) in NHS refuse is by itself sufficient reason for undertaking this review. In combination with the projected changes in legislation, the case for the review is unquestionable.

Design considerations

It is, of course, essential that any design solution for incinerator plant must reflect the parameters of the legislation etc. as outlined in Appendix A.

From the theoretical calculations based on the chemical formula for combustion of p.v.c., it can be seen that, when the proportion of this constituent in the refuse being incinerated is greater than 1·5% (approximate), the Alkali Act upper limit of 0·2 grains/ft^3 at STP (0·46 g/m^3 at 16° C and 1013 mb) for hydrochloric acid will be exceeded. Under these conditions such plant is likely to be deemed, by the Alkali Inspector, registerable under the Alkali Act, thereby imposing on the designer parameters which are much more stringent than those required under the Clean Air Act. These more stringent requirements will naturally be reflected in the capital and running costs for the plant produced by the designer.

These costs could be related to provision of such items as:

(*a*) moving grates
(*b*) cyclonic after-burner chamber
(*c*) waste-heat boiler
(*d*) wet scrubber incorporating water cleansing plant (to control HCL level etc. in discharge to drain)
(*e*) cyclonic or electrostatic filter.

The introduction of the waste-heat boiler would be necessary to decrease the temperature impinging on the cleansing devices through which the gases subsequently flow. The economic benefit of such a boiler is therefore entirely advantageous.

For *d*, it should be noted that cases can be quoted where, with relatively inefficient gas scrubbing plant, the pH of the water flowing to drain is 2. Should the operational policy of NHS premises be deliberately drawn up to control, in particular, say, the level of p.v.c. in the refuse being burnt to less than 1·5%, cost reductions might be made by excluding the wet scrubber from the design.

However, there remains the question of whether it is necessary, to meet the remaining parameters in Appendix A, to incorporate in the design, the features *a*, *b*, *c* and *e*. It is claimed by at least one local authority chief environment health officer that the operational record of firing one existing hospital incinerator which does not incorporate types *a*, *b*, *c* or *e* plant, has proved conclusively that the NHS refuse handled cannot be burnt in such plant within the legislation existing at present. The opening of doors to the combustion chamber and manual raking of the fire bed at frequent intervals has been identified as the part of the operation which causes the offences. The manufacturer claims that, with suitably trained operatives following the specified procedures, particularly during the 'raking' activities, all requirements of the law can be met.

The extent to which the design should make allowances for the deficiencies of operator performance, inaccuracies in prediction of analysis of refuse to be incinerated, changes in this analysis with time, future changes in regulations (Appendix A) etc. can affect fundamentally the design solution presented, and hence the ensuing costs.

Incineration costs

For a specified set of legal standards and given a fixed refuse analysis, the unit cost of incineration (say £/t) varies primarily with the scale of the operation.

A present-value exercise was performed to build up equivalent annual cost (e.a.c.) of incineration/tonne of refuse for three types of plant, each handling 562 kg of refuse per hour, 8 h/day, 6 days/week:

		e.a.c. £/t
(*a*)	conventional hospital incinerator, as operating at present, but in such a way as not to meet the requirements of the local-authority chief environmental health officer	22·8
(*b*)	NHS incinerator to comply with current legislation and good practice and giving heat recovery	39·3
(*c*)	as for (*b*) but without heat recovery	46·5

The above e.a.c. figures were assessed allowing for initial capital cost, capital cost of replacements and revenue costs (for fuel, labour, transport, maintenance, ash etc.). The interest rate used was 10%, the period was 60 years. Building, roads, plant, vehicles, mechanical and electrical services, and design-free costs were allowed for in the computations.

If the scale of operation is increased, the cost per tonne is considerably reduced. For example, a 300 t/day plant, without heat recovery at Florida, USA, operated at a cost of £2·50/t[3] at 1971 prices. Other figures quoted are £3–5/t at 1974 prices[1], £3·50/t at July 1973 prices[3] for a modern incinerator near Manchester and £7–9/t at 1974 prices.[4]

Cost of refuse disposal by controlled tipping

By local authorities

Controlled tipping is the major means by which local authorities dispose of the 16 000 000 t of domestic refuse[1] they collect annually in the UK. It is estimated that, of this amount, approximately 2·2% emanates from NHS premises, and that the NHS itself disposes of a further (about) 1·1%, mainly by incineration. D. Pearson indicated in 1974 that 'controlled tipping has annually been found by far the cheapest method at £0·5 to £1·0 per ton'.[1]

By private contractor

These local-authority costs are to be compared with those charged by a private contractor. A tender figure from a private contractor in July 1974, allowing for the cost of provision on site of a storage container and compactor, was £4400 p.a. for each of the first 3 years, during which the refuse would be removed in two containers (each 15 m^3) per week. The weight of refuse in each container is about 15 t. Thus the cost per tonne of refuse removed under the above contract in 1974 was £2·8/t, say, £3·5/t in 1975. This service can cover all types of NHS refuse, except that:

(*a*) pathology department wastes are sterilised in an autoclave prior to collecting for tipping

(*b*) animal carcasses, say, including those from veterinary surgeons' premises and identifiable human tissues, could be disposed of in a more socially acceptable way by a macerator unit connected to the local-authority soil-drainage system

(*c*) the small quantity (say 3 kg/week) of sputum samples (which are not autoclaved before leaving a pathology department) have been dealt with on one site by burning in the existing coal-fired boiler plant.

For a hospital site, where such an operational policy on refuse disposal has commenced, care has been taken to take into account the views of various authorities concerned with such activities. These authorities should include:

- the chief environmental health officer of the local authority
- the disposal of refuse officer of the local authority
- the district community physician of the area health authority
- the water authority for the area in which the private contractor tips the refuse
- other officers of the health and safety executive (e.g. related to safe working conditions for private contractor's workmen).

In the example referred to, the site for tipping used by the contractor is 'one of the few safe, approved and licensed sites for the disposal of chemical wastes—and large quantities of acids, alkalis, solvents etc. are deposited'. The site area is closed to the general public and outside contractors, and is situated in an isolated area on ground that was formerly a quarry for a brick works, is therefore a deeply lined claypit, all wastes deposited being contained within the pit, and it is considered that there is no chance of pollution of underground water by seepage, a view shared by the Thames Conservancy'.

The NHS refuse is tipped early in the morning and thus very soon afterwards is covered by refuse

Table 1 Cost of alternative refuse disposal services when applied to that part of NHS refuse which remains after the local authority removes domestic wastes free of charge

	Cost of l.a. collection and controlled tipping	Cost of l.a. collection and incineration	Cost of collection and tipping by private contractor	Cost of existing NHS incineration	Cost of future NHS incineration with heat recovery	Cost of future NHS incineration without heat recovery
	a	*b*	*c*	*d*	*e*	*f*
i Cost per tonne of refuse £	0·9	6·3	3·5	22·8	39·3	46·5
ii Cost per year for hospitals in Oxford (1383 t/y of waste), £	1250	8700	4800	31 500	54 200	64 200
iii Cost per year for Oxford RHA (4 times ii,), £	5000	34 800	19 200	126 000	216 800	256 800
iv Cost per year for NHS (30 times iii), £	150 000	1 044 000	576 000	3 780 000	6 504 000	7 704 000
v Proportion of ii, iii and iv which is revenue	1·0	1·0	1·0	0·56	0·05	0·28
vi Proportion of ii, iii and iv which is for fuel	0	0	0	0·10	−0·22 saving (on adjacent steam boilers)	0·05

Note:
- Under *a* and *b* it is assumed that the local authority makes a charge, over and above normal rates charges, to the NHS for this service.
- The penalty for failing to segregate domestic refuse is that the above costs in ii, iii and iv would be trebled.

tipped regularly throughout the remainder of that day. The site is operated under 'a strict control' by the contractor. It should be noted[1] that at various points in the country 'regrettably there have been deviations from good practice leading for example to cyanide scares of recent years. The inevitable outcome has been legislation, The Deposit of Poisonous Wastes Act, 1972 and further legislation is certain to follow'.

It is appropriate to draw attention to the fact that NHS refuse can contain certain radioactive wastes for which properly controlled procedures for disposal will be required.

The private contractor may employ the use of compactors to minimise his storage, collection, transportation, tipping and associated cost and environmental problems. Hospital refuse has a density[5] of approximately 200 kg/m^3. This can be reduced in volume by a factor of five by compaction (Reference 6 quotes a factor of 15).

Costs of maceration and wet-disposal systems

Maceration and wet-disposal systems have been installed in high-rise blocks of flats but, even with the high population densities prevailing, the high capital cost[7] involved has greatly limited the number of applications in existence. For hospitals which are generally of low rise and comprising isolated buildings, such a system does not lend itself to widespread use throughout a site (nor, hence, the NHS).

This approach has not therefore been considered as a viable alternative to incineration and controlled tipping as a means of refuse disposal throughout the NHS. It is accepted, however, that, for a particular type of new building scheme, e.g. a high-rise residential block, an economic case might be made for such an installation being proposed.

Cost comparisons

Table 1 sets out the costs of each of the systems of refuse disposal considered.

Recommendations

The NHS should pursue refuse-disposal policies of segregation and controlled tipping (alternatives *a, c* in Table 1 in that priority order).

Thus the NHS should not proceed with:

- erecting further incinerators to dispose of growth in NHS refuse loads
- replacing any existing incinerators used to dispose of NHS refuse
- continued operation of existing incinerators used to dispose of NHS refuse

except in very extreme circumstances.

References

1 Pearson, D.: 'The economics of waste reclamation and disposal', *Chartered Mech. Eng.*, June 1974
2 Winch, G. R.: 'Design of incinerators', *Building Services Eng.*, June 1974
3 Winch, G. R.: 'Design of incinerators (correspondence)' *ibid.*, September 1974
4 Brown, E. M.: 'Design of incinerators (correspondence)' *ibid.*, September 1974
5 HSE Data Sheet MW 2.21, paragraph 12
6 HSE Data Sheet MW 2.8, paragraph 5.4
7 Courtney, R. E., and Sexton, D. E.: 'Refuse collection from houses and flats by pipeline', *Building Research Station*, 1972
8 Control of Pollution Act, 1974

Appendix A Résumé of legislation and good practice as applied to incinerators

1 *Clean Air Acts*, 1956 *and* 1968

Under the Clean Air Act it is an offence to emit dark smoke from any chimney. A later emission constitutes a separate offence. Dark smoke is defined as being as dark as, or darker than, shade 2 of the Ringlemann Chart.

For an emission from a chimney, if it can be proved that dark smoke emerged, owing to one or more of the following causes, the defence stands:

(*a*) lighting up from a cold furnace
(*b*) some unforeseeable and unavoidable failure of the furnace or equipment
(*c*) the use of unsuitable fuel (suitable fuel being unobtainable) provided this fuel was the least unsuitable that was available.

In addition to proof, the defence has to show that everything possible had been done to reduce the emission of dark smoke to a minimum.

Grit arresting plant must be installed in all new furnaces burning at a rate of more than 366 kW (1 250 000 BTU/h) any liquid or gaseous matter.

Chimney heights are controlled by local authorities under the 1956 Clean Air Act Memorandum, 2nd Edition 1956.

The above Acts exempt any work subject to *The Alkali Act*, from the provision of Clauses 1–16 and 1–10 of the 1956 and 1968 Clean Air Acts.

Under the Clean Air Act, the Secretary of State is given powers to make regulations in respect of all emissions including toxic gases. It is felt that, by the end of 1975, the recommendations of the Second Working Party (Appendix A, Section 4) will become such a regulation.

In the meantime the DoE recommend that particulate matter should not exceed a concentration of 0·2 grains/ft^3 at STP (0·46 g/m^3 at 16° C and 1013 mb). This and other criteria are used by chief environmental health officers in making recommendations to their local authorities on applications submitted to them.

For example, the qualifications attached to a recent approval were that 'grit and dust must not exceed 3 lb/h (1·4 kg/h), H_2S not to exceed 5 parts in 10^6 (as stated in the Chief Alkali Inspector's Annual Report, 1966), SO_2 not to exceed 3·5 lb/h (1·6 kg/h), the stack to be insulated to prevent the emission of acid smut, 4 in BSP sampling sockets to be provided, fuel oil of 35 s viscosity to be used and hospital and animal house waste to be burnt'.

2 *Alkali Act*

Under the requirements of the Alkali Act 'Works for the destruction by burning of chemical wastes containing combined chlorine, fluorine, nitrogen, phosphorus or sulphur' need to be registered.

Before operation can begin, suitable plant has to be installed for dealing with gaseous and particulate emissions. The design of the plant should be such as to render it capable of meeting the following conditions:

(*a*) the plant shall be operated smokelessly
(*b*) the statutory limit for hydrochloric acid, 0·2 grains/ft^3 at STP shall not be exceeded
(*c*) complete removal of chlorine should be attempted, but emissions not greater than 0·1 grains/ft^3 of chlorine at STP are tolerated
(*d*) the emissions are to be free from persistent mist
(*e*) fume emission shall not exceed 0·05 grains/ft^3 at STP
(*f*) emission of residual organic chlorine compounds to be less than 10 parts in 10^6 in the final emission. A suitable chimney height shall be provided which is influenced by local conditions
(*g*) there shall be no droplet emission
(*h*) sampling points shall be provided with suitable access for stack gas analysis

The threshold limit value (t.l.v.) (quoted below under 'the Factories Act') for HCl is too high for the more prolonged exposure of the general community, encompassing infants, the elderly and the infirm. The alkali inspectorate, in determining chimney heights, look for a maximum ground-level concentration of 0·16 parts in 10^6 (1/30 of t.l.v.).

This figure of 0·16 parts in 10^6 for hydrochloric acid may be too high if its effect is added to that of other toxic pollutants.

3 *Factories Act*

No direct legislation exists. However, the DoE HM Factory Inspectorate (DoE Technical Data Note 2/71: Threshold limit values, HMSO) do have a t.l.v. for hydrochloric acid. This is set at 5 parts in 10^6 and refers to a time-weighted concentration for a 7–8 h workday, 40 h week and represents conditions under which it is believed that nearly all healthy workers may be repeatedly exposed without adverse effect (see ground-level concentration figure quoted under the Alkali Act, Section 2).

4 *Report of the Second Working Party, Department of the Environment*

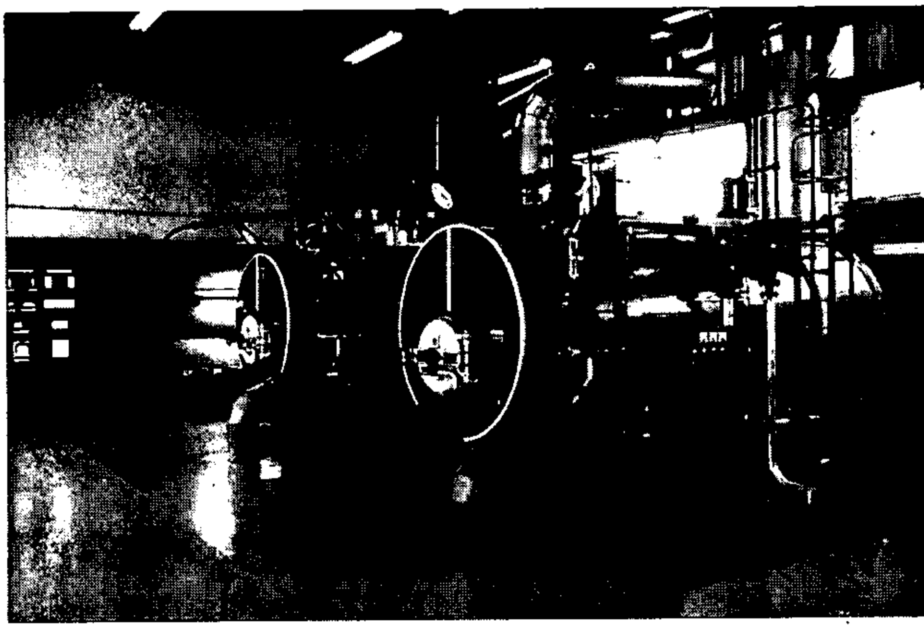
The Second Working Party's recommendation on acceptable levels of grit and dust varies according to the heat release levels. For example, with a plant releasing 10 500 000 BTU/h the grit and dust level should not exceed 0·3 grains/ft^3 with flue-gas conditions standardised at 10% CO_2, NTP, dry. As stated above, it is felt that by the end of 1975, these recommendations will have become 'regulations' under the Clean Air Act.

The Working Party recommends that owners of existing plant should be given 5 years grace before modifying the plant to perform to the standards they have recommended.

5 *Public Health Act*

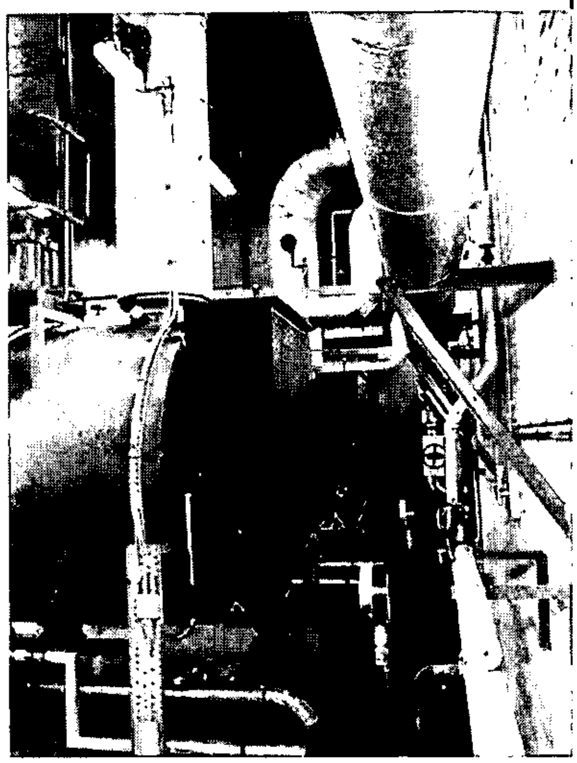
The Public Health Act gives local authorities power to prevent nuisance from dust, ashes, rubbish and for regulating the removal through the streets of offensive matter or liquids.

It should be noted that the application of the above Acts come, under the Health & Safety Executive, which grants power to the offices of the alkali inspector, the local authority environmental health officer etc. for local implementation.



New-look boilerhouse

The lower picture shows the grit arrestors and the pipe at the bottom through which grit from flue gases is recirculated to the combustion chamber finally to be burnt



In 1971, when modernisation of the Montagu Hospital, Mexborough, was first discussed, the old coal-fired boiler plant was due for renewal and its site was needed for hospital extensions. Coal was chosen on fuel-cost grounds though gas and oil were also considered. The building is designed to take three GWB Vekos boilers but so far only two have been installed, each of 1·68 MW (5700 lb/h of steam). The third boiler will be installed whenever the need for it is firmly established, which is likely to be soon.

The first Montagu Hospital was built in 1904. Current modernisations and extensions are largely completed for this acute general hospital of 191 beds, with an accident and emergency department. A new outpatient department is being built as well as a new linen store and mortuary. The geriatric day unit is nearly complete, so are the upgraded operating theatres, the new boiler plant and the new services throughout the hospital, including new pipes for steam and hot water and electric cables. The hospital was originally built on land given by Andrew Montagu of High Melton Hall nearby, was extended in 1924, and the capital for the present extension costing £530 000 (including £80 000 for the boilerhouse) was provided by the Trent Regional Health Authority.

The new boilerhouse provides all the heat needed for the hospital, including central heating, sterilising, domestic hot water and cooking. Both domestic and central-heating waters are heated in steam-to-water calorifiers. All space heating is by hot water. Some steam is provided at a lower pressure than the boiler pressure (100 lb/in^2) for autoclaves and kitchen equipment.

Instruments in the boilerhouse indicate the carbon dioxide in the flue gas, the chimney draught, the flue gas temperature and the smoke density. The boiler plant is about 75 m from the nearest hospital building and the steam passes underground to it through ducted mains. The circular reinforced concrete chimney contains four flues, three for the boilers and one for the nearby hospital incinerator.

The 60 t bunker receives its coal pneumatically through 12·7 cm-diameter pipes to which connection is made from the delivery lorry and its compressor. This method of fuel delivery is clean and dust free. Air conveys the fuel from the bunker to the boiler and is also used for burning the coal. The coal is 1·25–2·5 cm in size (Brodsworth washed singles) and about 1500 t per year are used.

Boiler operation is smoke free despite wide fluctuations in load pattern. A built-in grit arrestor removes grit from the flue gases before they enter the chimney.

continued on page 9

The collected grits are refired in the boiler so as to burn any fuel remaining in them. The efficiency of the boiler exceeds 80% based on the gross calorific value of the fuel throughout its modulating range of 3 to 1.

Smoke-density monitor and other instruments

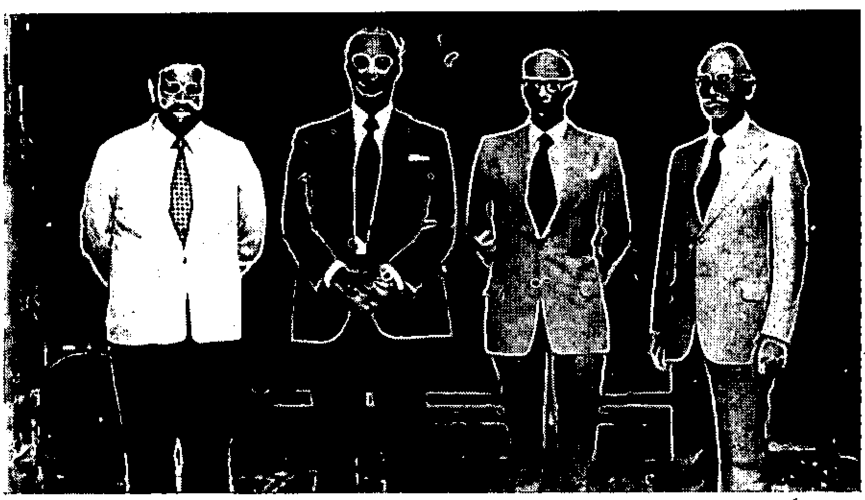
The rate of feed of fuel and the amount of air delivered to the boiler depend on the heat demand at any particular time, and are completely and automatically controlled. The ratio of fuel to air is correctly proportioned to ensure high efficiencies throughout the modulating range. If the demand on the boiler is below the normal operating range, an overriding pressure switch cuts off the coal and air feeds. When the heat demand increases, the pressure switch causes the boiler to increase the fuel and air supplies exactly in proportion to the new heat requirements. Modulation is this exact suiting of the fuel and air supply to the demand.

Maintenance of all parts of the boilers and coal-handling equipment is simple, and, since there are no moving parts within the furnace or other hot areas of the boiler, wear and tear is at a minimum.

The main contractor for the modernisation and extensions is Bradbury Construction Ltd., Sheffield. Boiler-house mechanical services were put in by J. Dixon (Mechanical Services) Ltd., and electrical services by T. W. Sampson; the boiler controls were installed by Benson Controls Ltd., Normanton, and the Vekos boilers were provided by Parkinson Cowan GWB Ltd., Dudley, Worcs.

A visit to Falfield

Senior members of the Institute recently visited Falfield, the NHS engineering training centre in Gloucestershire. The photograph shows (from left to right) J. W. Barnes (Principal of the Training Centre and a member of Council), F. H. Howorth (President of the Institute), R. Manser (Assistant Chief Engineer, DHSS, and a Past-President), and K. I. Murray (Assistant Chief Engineer, DHSS, and a member of Council).



Institute news

WEST OF SCOTLAND BRANCH

The branch has arranged the following winter programme:

1975

30 Oct.

Coal's contribution to the efficient use of energy by J. Hunter, National Coal Board

27 Nov.

Recent developments in measurement and control by J. Brown, University of Strathclyde

18 Dec.

Visit to the studios of the Glasgow & West Hospital Broadcasting Service

1976

29 Jan.

Solid-state communications for hospitals by M. Bloxwich, B. Chapman and R. G. A. Griffiths, Static Switching Ltd.

26 Feb.

Electrical safety equipment with special emphasis on earth-leakage protection by F. E. Waspe, Siemens (UK) Ltd.

25 Mar.

A.G.M.

29 Apr.

Subject to be arranged

All sessions except those on the 18th December and 25th March are open to visitors, and will be held in the Conference Room of the Greater Glasgow Health Board Offices, 351 Sauchiehall Street, Glasgow, commencing at 7.30 p.m. Entry is by the Holland Street entrance.

HE News

BSES meetings

The following programme of meetings has been arranged by the Building Services Engineering Society.

1975

30 Oct.
Proposed joint meeting with JBG/JLO

11 Dec.
Proposed lecture: **The fundamentals of professional liability**

1976

29 Jan. or 12 Feb.
Proposed lecture: **The contractor/sub-contractor relationship**

10 Mar.
Joint meeting with IES. Lecture: **Lighting and thermal comfort**

6 May or 13 May
Proposed joint seminar with DoE on **Building Regulations**

All of the meetings except that on the 10th March will be held at the Institution of Civil Engineers, 1-7 Great George Street, London SW1P 3AA. The 10th March meeting will be held at the Royal Institution, Albemarle Street, London W1.

Good response for laundry exhibition

The new National Exhibition Centre at Birmingham is to be the venue of the 1976 International Laundry Cleaning Equipment & Services Exhibition.

There will be particular emphasis at the exhibition on high-production laundry plant for servicing hospitals, textile-rental facilities and industrial-cleaning operations. New ideas in plant and machinery, some of which have been introduced in prototype form at specialised hospital and industrial shows in various parts of the world, will be displayed in practical form under one roof. By the beginning of September, over 50 applications for stand space had been received by the organisers.

The exhibition, which will be held from the 17th to 24th June 1976, is sponsored by the Society of Laundry Engineers & Allied Trades Ltd., supported by the European Laundry & Dry Cleaning Machinery Manufacturers Organisation. Further details can be obtained from the organisers, Industrial & Trade Fairs Ltd., Radcliffe House, Blenheim Court, Solihull, West Midlands B91 2BG.

SWITCHBOARD SYSTEM

A contract worth more than £22 500 for a p.a.b.x. switchboard system has been awarded to Telephone Rentals by the Solihull Health Authority. The system is to be installed at Hollymore Hospital, Northfield, Birmingham, and will include 150 extension lines, night service and power-plant equipment.

Saving energy

A presentation of energy-conservation equipment and techniques is to be held at the US Trade Centre, London, from 25th to 27th November. Further information and invitations are available from Armca Specialties Ltd., 19-20 Cowcross Street, London EC1M 6DQ.

Emergency-lighting seminar

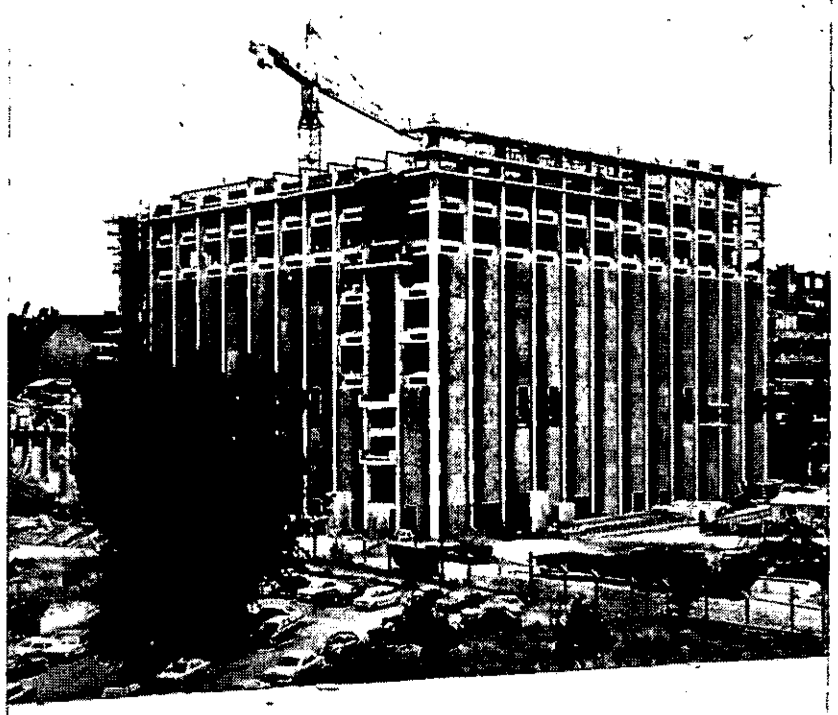
A seminar on the emergency lighting of escape routes from public buildings is to be held on the 4th November, 1975, at the Mount Royal Hotel near Marble Arch, London. The decision to hold the seminar, which is sponsored jointly by the Lighting Industry Federation and the British Electrical & Allied Manufacturers' Association, was prompted by the publication of BS 5266 'The emergency lighting of premises: Part 1'.

Further information is available from Bob Hobbs, Promotion Services Department, British Standards Institution, Maylands Avenue, Hemel Hempstead, Herts. HP2 4SQ.

Medical school at Leeds

The new medical-school building being built by John Laing Construction for the University of Leeds is now taking shape. The building will consist of a deep-plan 8-storey block, housing a self-contained dental hospital for outpatients on the ground floor, and nine university medical departments above, together with a connected 2-storey lecture-theatre block containing preclinical and dental lecture theatres.

The architects for the scheme, which is due for completion in summer 1977, is the Building Design Partnership.



Natural ventilation of large hospital buildings

by P. J. JACKMAN and I. N. POTTTER

Wind-tunnel tests of hospital scale models and a computer program to calculate internal air-flows were used to produce a prediction technique to determine the rates of natural ventilation of large hospitals. The technique was applied to a Harness hospital design and this article reports that the ventilation generated by wind forces in, for instance, ward areas would not be consistently adequate for the comfort and well-being of the occupants.

In the past, the supply of fresh air to hospital ward areas has normally been provided by natural ventilation. Recent trends in large hospital design have, however, given rise to some concern over the effectiveness of natural ventilation in producing continually adequate air-flow rates for the comfort of the occupants.

In particular, the 'deep-plan' type of layout leads to ventilation problems. The incorporation of courtyards into such designs was thought to promote natural ventilation as well as provide increased use of daylight through the additional exterior surfaces.

Such a design concept is embodied in the Harness hospital schemes proposed by the UK Department of Health & Social Security. The Harness designs are large complexes up to four storeys high, which, in plan, basically consist of 15.m square structural modules interspersed with 15 m square courtyards (Fig. 1).

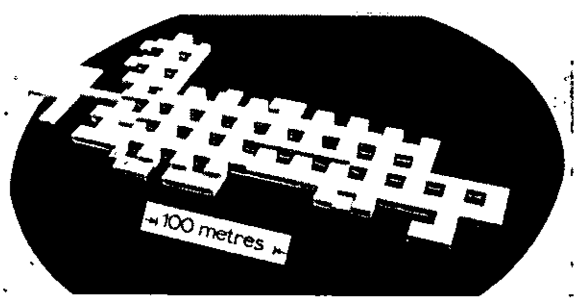


Fig. 1 Model of a typical Harness hospital

The natural flow of air into a particular building is dependent on the influences of wind and temperature differences. For large irregularly shaped buildings these influences are difficult to predict, and the calculation of the ventilation rates in all the internal areas is a complex procedure.

Natural forces

The two motive forces primarily responsible for natural ventilation are generated by the effects of temperature differences and wind impingement.

The difference in temperature, and hence in density, between the air inside a building and that outside causes a movement of air vertically through the building via openings such as lift shafts and stairwells. This temperature motivated transfer of air is called the 'stack effect'. The direction of air transfer will depend on whether the outside temperature is less or greater than the inside air temperature. If, for instance, the air temperature within the building is higher than that outside, a pressure lower than that outside is produced in the lower part of the building with an inward and upward flow of air as a consequence. Air flows outward from the upper levels of the building (Fig.2). The reverse occurs when the indoor air temperature is lower than that outdoors.

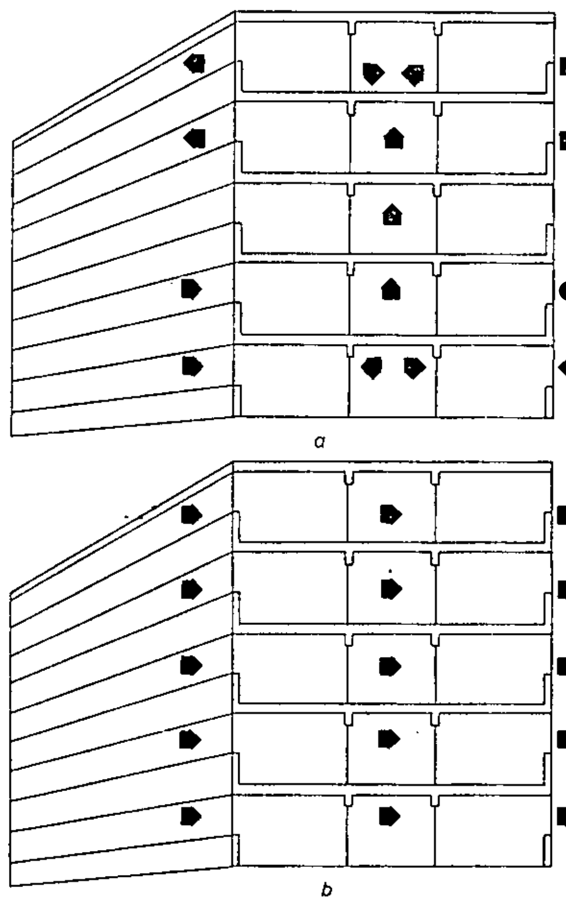


Fig. 2 ***a*** **Effect of temperature differences**
b **Effect of wind**

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The differences in pressure within a building resulting from stack effect may be calculated from a knowledge of the temperature difference and the vertical distances between openings in the facade of the building.

The Harness hospitals under consideration were either three or four storeys high with a floor-to-floor height of 3·8 m. In such buildings, the maximum pressure difference at an indoor-to-outdoor temperature differential of 20 deg C would be about 13·5 Pa. This pressure difference is equivalent to the effect of a light wind, but because of the restriction of air flow from the rooms of one floor to the next, the wind effect, which produces a basically horizontal flow of air across a building, is normally the most predominant.

The effect of wind impinging on a building is to produce a positive pressure on the windward side(s) and a negative pressure on all other sides, including the roof. The pressure differences so generated give rise to movement of air through openings or cracks on the windward face(s), across the building and out through the other faces.

The characteristics of wind vary with time and location. For instance, the prevailing wind direction differs from place to place as does the frequency of various wind speeds. The effect of local terrain on the wind pattern is also significant. The range of local wind speeds is likely to be much higher in a countryside location than in a suburban area and still higher than in a city centre. In some instances, neighbouring tall buildings or other local prominent features in the landscape modify the wind pattern still further. These many variables make the prediction of the wind effect much more difficult than temperature effects.

The situation is further complicated by the variation of surface pressures generated by the wind depending on the orientation, external shape and dimensions of the building itself. For buildings of the complexity of the Harness design, it was necessary to determine the wind pressure distribution around the outside of the buildings experimentally by using wind-tunnel testing techniques.

Wind tunnel testing

In a wind tunnel it is possible to simulate the natural wind either by modelling the local terrain over which the air passes or by installing screens which produce a similar effect (Fig. 3). Scale models of the particular Harness hospital complexes were constructed and installed in the wind tunnel (Fig. 3). The models incorporated 500 or more tiny pressure tubes terminated at the building surfaces. These pressure tubes were connected to a manometer system, so that the individual pressures could be measured.

Fig. 3 Dudley Harness hospital model in a wind tunnel

The wind-tunnel tests were conducted with the models set in a series of 12 angular positions at 30° intervals to study the effect of variations of wind direction.

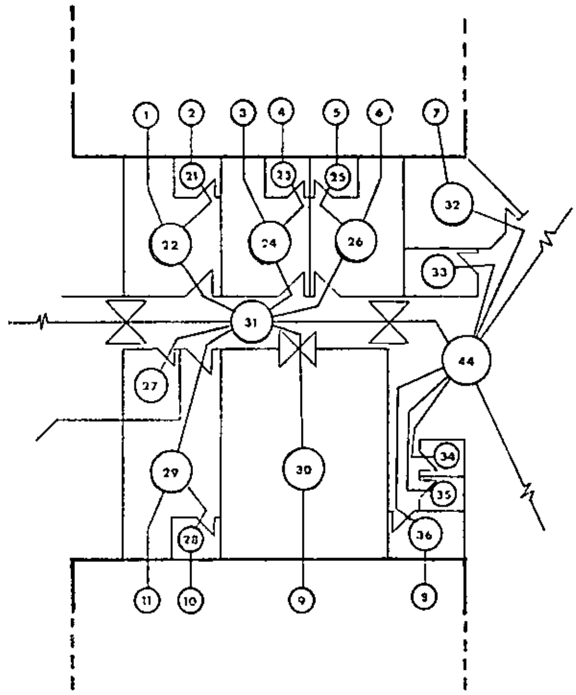


Fig. 4 Air-flow network

Internal airflow network

The pressure distribution on a building is an important factor in assessing ventilation rates, but there are other parameters which need to be taken into account. The rate at which air flows into and through a building under the influence of wind is governed by the 'leakiness' of the structure itself. Air finds its way in through open windows, external doors, specially provided apertures, if any, and through adventitious cracks between cladding components. Within the building, the air-flow paths consist of rooms and corridors, which may not be separated by internal doors. The rate that air passes through this complex network of flow paths depends on the resistance of the individual components and their relationship to one another (Fig. 4).

The components through which the air passes are normally doors and open windows (which leak even when they are closed). Available experimental data on the air-leakage characteristic of standard windows and doors were used in the calculations described below.

Computer program

The number and complexity of the air-flow paths, particularly in a large hospital building, necessitate the use of computer techniques to calculate the ventilation rates. A computer program, entitled CRKFLO and developed by BSRIA, was used in this study to calculate the air-flow rates, directions of flow and corresponding internal pressures that would be generated by the wind-pressure distributions derived in the wind-tunnel studies. Additionally, the program allowed the effect of the mechanical ventilation on toilets, bathrooms and other specific areas to be incorporated. A block diagram illustrating the input requirements of the program and the resulting outputs is shown in Fig. 5.

The natural ventilation of the wards was of particular interest and Fig. 8 shows the results calculated for a transverse wind direction with all the internal doors closed and all windows open by 12·5 mm. This setting of windows and doors was chosen to represent the situation in winter.

Fig. 8 clearly shows the effect of that mechanical ventilation of the service areas which, at zero wind speed, produced a ventilation rate between 0·5–1 air change in 70% of the ward areas and less than half an air change per hour in all but a fraction of the remaining ward areas. At the higher wind speeds, the influence of the mechanical ventilation decreased, and greater rates of ventilation were produced over a large proportion of the ward areas. However, even at a wind speed of 7 m/s only 30% of the ward areas were ventilated above a rate of 2 air changes/h and less than 10% above 3 air changes/h. The calculated ventilation rates (air changes/h) and the directions of air flow for the naturally ventilated areas of the zone are included in Fig. 7 for the wind speed and direction indicated.

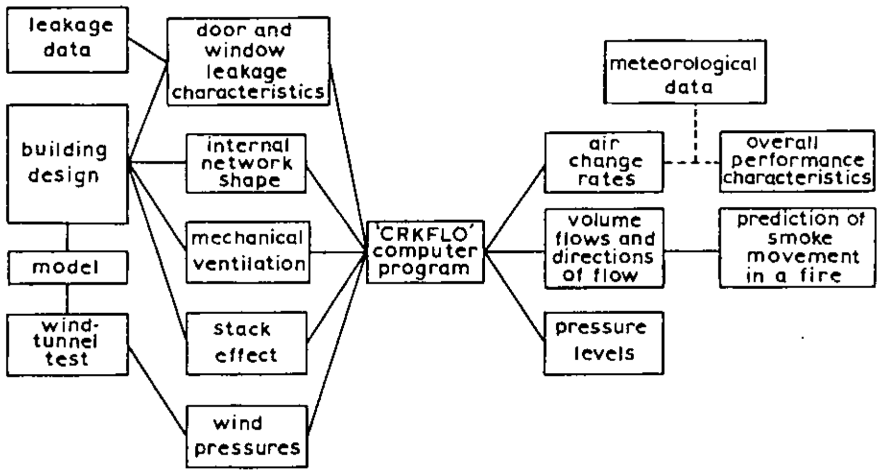


Fig. 5 Ventilation rate calculation process

Natural ventilation performance

The CRKFLO program was used to study the ventilation in several hospital designs under a wide range of conditions. For the purposes of this paper, however, the discussion of the results will be centred on one hospital design and on one typical zone within that hospital. The conclusions drawn are, nevertheless, representative of the overall findings. The layout of the selected hospital is shown in Fig. 6 on which the location in plan of the particular zone is also indicated.

The zone comprised a 1st-floor 124-bed ward area (Fig. 7). In it are three open-plan 16-bed wards, one 8-bed ward, four 6-bed wards, four 4-bed wards, two 2-bed wards and 24 single-bed wards. The diamond shape in the centre of the cruciform sections denote service areas and nurse stations, which were provided with mechanical ventilation. The bathrooms and some of the toilets (those with no external walls) were equipped with extract ventilation systems. Overall, there was a greater rate of mechanical air extract than supply.

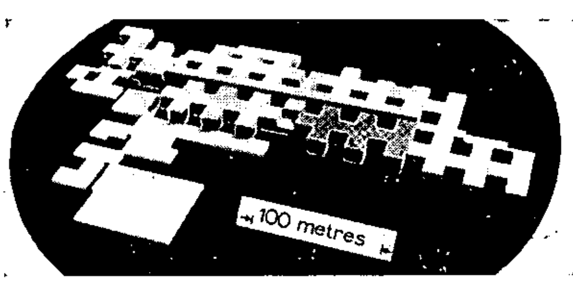


Fig. 6 Location of ward block shown on hospital model

To examine the effect of size and location of the wards, the single-bed and 6-bed wards will be considered separately. In relation to the wind direction shown in Fig. 7, some of the single-bed wards are located in each of the following positions:

- with windows on a leeward face within a courtyard
- with windows on a face parallel to the wind direction and within a courtyard
- with windows on a windward face
- with windows on an external face parallel to the wind direction.

For each of these positions, the variation of ventilation rate with wind speed is plotted in Fig. 9. At zero wind speed, a ventilation rate of about 0·8 air changes was produced in all the single-bed wards. This was the result of the mechanical ventilation in the service areas and, because there was a higher extract ventilation rate than supply, air was entering each ward from outside (infiltration).

In the wards which face the courtyards, the infiltration rate decreased as the wind speed was increased. This was the result of the pressure differences generated by

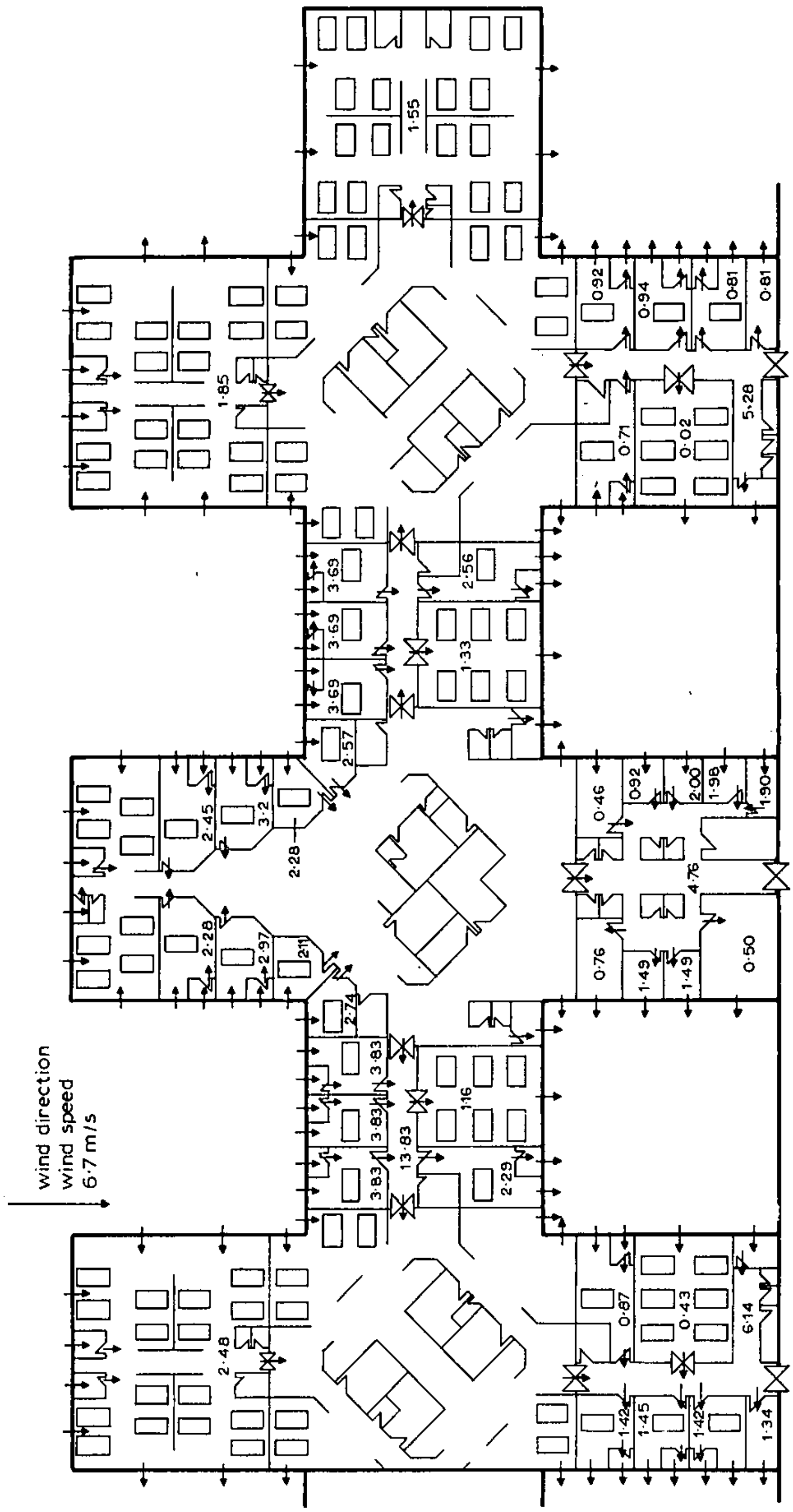


Fig. 7 Ward area (adult acute) plan and calculated ventilation rates

the wind acting in opposition to the flow produced by the mechanical ventilation. As curves *a* and *b* of Fig. 9 show, at the higher wind speeds, complete reversal of flow occurs, so that air passes from the corridors into the wards and then outside (exfiltration). Curves *c* and *d* (Fig. 9) demonstrate the effect in the externally located single-bed wards where the natural ventilation was in the same direction as the mechanically induced ventilation.

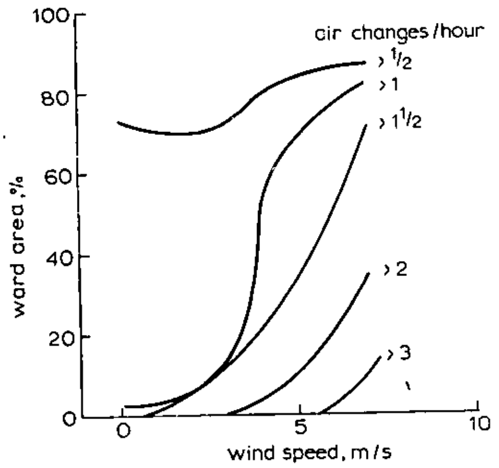


Fig. 8 Ventilation in ward areas (adult acute)

The 6-bed wards were situated either:

- with windows on a leeward face within a courtyard
- with windows on a face parallel to the wind direction and within a courtyard.

The curves of ventilation rate related to wind speed are plotted in Fig. 10. They show similar characteristics to curves *a* and *b* for single-bed wards except that the 6-bed ward's ventilation was significantly lower.

Whole hospital ventilation

The results described above relate to only a variation in wind speed and to one wind direction. To assess the overall natural ventilation performance it was necessary to examine the frequencies of occurrence of various combinations of wind speed and direction. On considering the whole hospital, it was found that, because of its elongated shape, crosswinds produced substantially more ventilation than end-on winds.

Meteorological data was thus analysed to establish the proportion of time winds occurred at various speeds and from the various directions in the quadrants corresponding to cross- and end-on orientations (Fig. 11). This was done only for outdoor temperatures less than 10° C because it was assumed that, at high temperatures, it would be possible to increase ventilation by opening windows wider than the assumed 12·5 mm without causing discomfort from cold draughts. Fig. 11 shows the resulting plot for the Birmingham site of percentage time against wind speed, which indicates that the occurrence of crosswinds was similar to that of end-on winds. The mean line was used for the succeeding analysis.

From the graphs it may be noted that the proportion of the time that the wind speed exceeded zero was 50%. The other half of the time consisted of 10% calm and 40% in excess of 10°C.

Using this wind data and the computed ventilation rates of the whole hospital for both cross and end-on winds at various speeds, the chart in Fig. 12 was derived. The continuous lines show the calculated ventilation performance with all windows slightly (12·5 mm) open. Window closure would, of course, considerably decrease ventilation rates, but opening them may generate intolerable cold draughts at outdoor temperatures below 10° C. This latter effect depends somewhat on the form and capacity of the heating appliances in each room. The postulated effects of increasing the window opening for periods of the year when temperatures are higher than 10° C are shown as dotted lines.

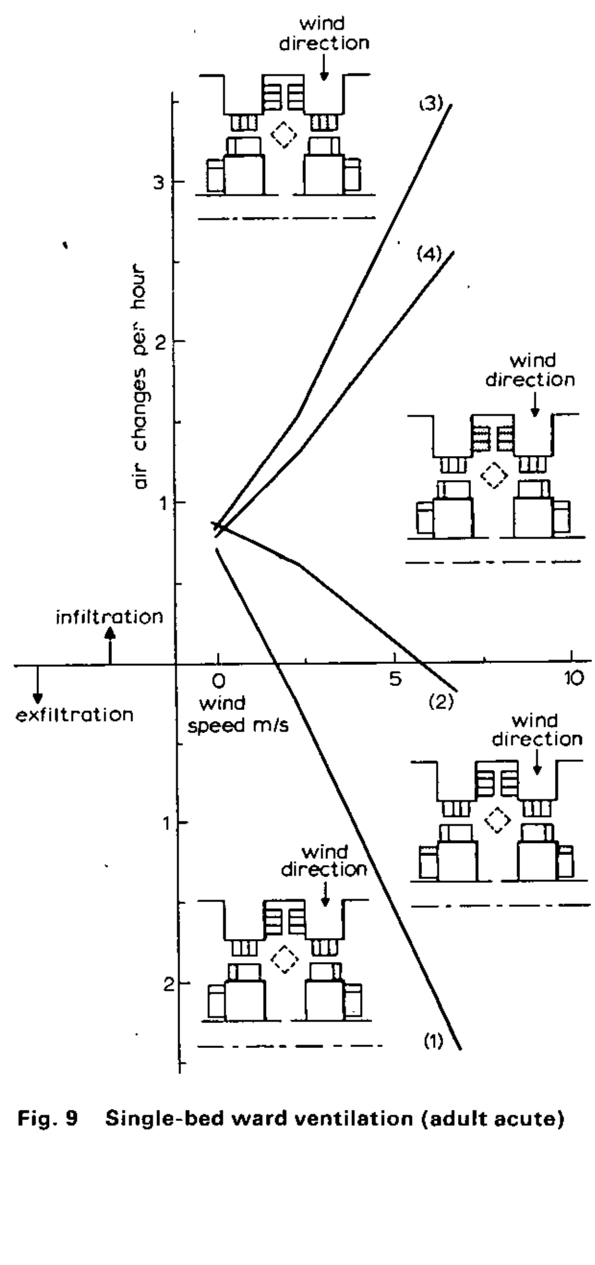


Fig. 9 Single-bed ward ventilation (adult acute)

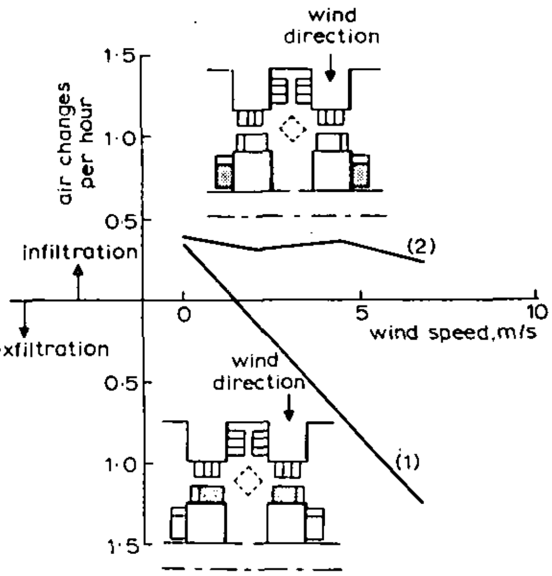
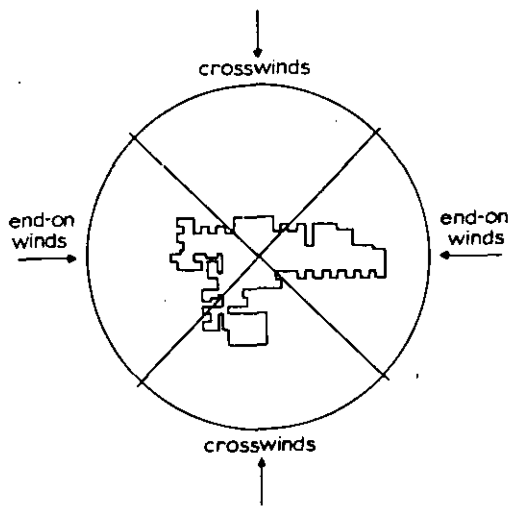


Fig. 10 Six-bed ward ventilation (adult acute)



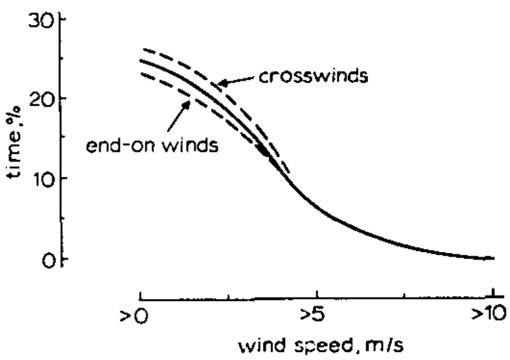


Fig. 11 Frequency curve of wind speeds

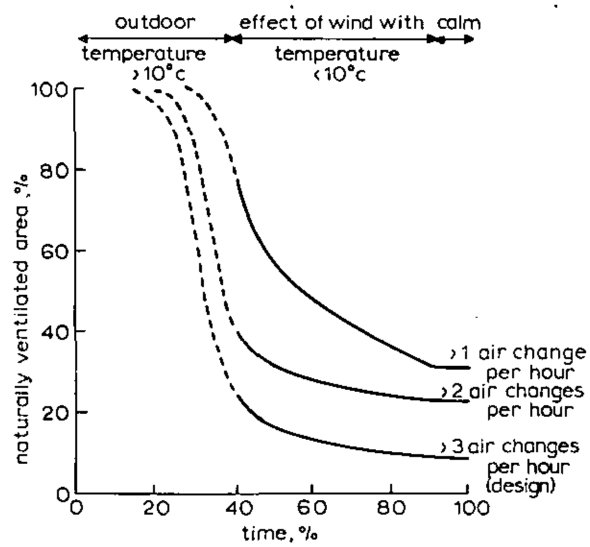


Fig. 12 Natural ventilation performance of a four-storey Harness hospital sited at Birmingham

The chart indicates, for example, that only 50% of the naturally ventilated area of the hospital will have a ventilation rate greater than 1 air change/h for about 45·5% of the time. Similarly, it may be predicted that, for 70% of time, natural ventilation rates of greater than 1 air change/h will occur in only 40% of the hospital, rates greater than 2 in 25% of the hospital and rates greater than 3 in about 10% of the hospital.

Although 2 air changes/h may be considered an acceptable rate of ventilation for normal circumstances, it has been suggested* that 3 air changes/h is more appropriate for hospital wards. It is clearly predicted from the above results that natural ventilation rates will be below this minimum acceptable for much of the time.

The results of this theoretical study thus reveal the general inadequacy of wind forces to produce consistently adequate levels of ventilation in large deep-plan hospital buildings. It would therefore appear necessary to employ mechanical ventilation, at least in areas where the maintenance of fresh-air supplies at all times is important.

The use of the ventilation-prediction technique has ensured that the opportunity for making the provision of mechanical ventilation was available while the buildings were still in the design stage.

Acknowledgments: The authors wish to express their appreciation to the UK Department of Health & Social Security, which sponsored this work, for its permission to publish this article, and, in particular, members of the chief engineer's staff who supervised the project.

WARD LOCATION

(*a*) With windows on a leeward face within a courtyard
(*b*) With windows on a face parallel to the wind direction and within a courtyard
(*c*) With windows on a windward face
(*d*) With windows on an external face parallel to the wind direction.

*British Standard Code of Practice CP3, 1950, Chap. 1 (c).

Engineering and medicine

S. R. MONTGOMERY, M.A., Sc.D., C.Eng., F.I.Mech.E.

To an outside observer there may appear to be little in common between the work of an engineer in charge of the operation and maintenance of essential building services and the work of an engineer in a university carrying out clinical research in collaboration with doctors, apart from the fact that both activities take place in a hospital. This article considers the viewpoints of various interested observers and presents some observations on the fundamental problem facing both hospital and medical engineers—what is meant by health and how can engineering contribute to its enhancement?

Chambers Dictionary defines a hospital as 'a building for the reception and treatment of the old, the sick and hurt . . . etc., or for the support and education of the young; a lodging (Spenser)'. The Oxford Dictionary has several definitions including a 16th century use of the word to mean 'a house of entertainment'! The relevant definitions for our present study are 'an asylum for the housing and maintenance of the needy' (e.g. geriatric hospital) and 'an institution or establishment for the care of the sick and wounded or of those who require medical treatment'.

The Encyclopaedia Britannica (11th edition) has a long and detailed article on hospitals, and it indicates that the word derives from the Latin *hospitalis*, the adjective of *hospes*, meaning either a host or his guest. In France, there is a clear distinction between the terms 'hôpital' and 'hospice', which refer, respectively, to accommodation for the sick and infirm of a temporary or permanent nature. The word 'hôtel' is used to describe other public accommodation. The original derivation from *hospes* indicates clearly the essential feature of all these institutions in which there are hosts and their guests.

The following is a précis of part of the article:

'Originally hospitals were unsystematic, crowded, ill-organised necessities which wise people refused to enter, if they had any voice in the matter. They were merely a building or buildings where sick and injured people were retained and, more frequently than not, died. Now that operative interference is the rule rather than the exception in the treatment of hospital patients and with the introduction of antiseptic and aseptic methods, the mortality in hospitals is probably materially less than it is among patients attended in their own homes. At the present time in all large cities and crowded communities of civilised countries, great hospitals have been erected on extensive sites which are so planned as to constitute a village with many hundreds of inhabitants. In Europe buildings are usually of one storey: in the United States owing to the difficulty of obtaining suitable sites and for reasons of economy some competent authorities strenuously advocate high buildings with many storeys for town hospitals.'

The 11th edition was published in 1910, and the article was written by Sir Henry Burdett, at one time superintendent of Queen's Hospital, Birmingham. Some of his other ideas on the ideal hospital were somewhat extreme, such as the complete isolation of a hospital in the country, remote from the community. Isolation from local infection was felt to outweigh the lack of convenience for patients and their families. The t.b. sanatoria erected in memory of King Edward VII are typical examples. However, it is the present day hospitals in Britain with which one is really concerned, not so much with their methods of construction and the equipment they contain, but rather the way in which they actually function from day to day.

Hospitals and the local community

One can start by considering the organisation within which the hospital operates in Britain, namely the Department of Health & Social Security (DHSS). This is the largest organisation in Britain with more than 900 000 employees, which is twice as large as any other national body and three times as large as the largest private company.

A major reorganisation took place last year, the first since the National Health Service was created in 1948. The aim was to rationalise the management structure covering all the health services supplied, not only within the hospital, but also many services previously the responsibility of the local authority who now retain control only of certain social workers. There are now Regional and Area Health Authorities subdivided into districts where the management team, family practitioner committee and community health councils are responsible for the detailed running of the local health services. Within the individual district hospital an administrator is in charge of the various medical, paramedical, technical and administrative groups which ultimately supply the services required by the individual consultants.

But for whose benefit is the hospital provided? For the doctor? Surely it must be for the patient, who all too often can be forgotten. The district health service has a responsibility to provide the facilities required to deal with the medical and social needs of all the members of the community whose geographical boundaries it shares. With perhaps 250 000 inhabitants the community is large enough for statistical methods

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to be used in predicting its overall health needs; and it is certainly desirable that the health service be a properly integrated component of the community since it will employ some 5000 people locally, not only in hospitals, but also in ambulance services, family planning, maternity and child health clinics, to name only a few.

Any individual member of the community may need to use one or more of these services and we shall consider, as a case study, one particular example of an individual whose heart valves become defective, to illustrate how the work of the engineer influences the progress of such a patient both in and out of hospital, from sickness to health. Admittedly, the example is fairly extreme, and is atypical in that relatively few district hospitals would have the necessary facilities or the demand to enable them to carry out operations of this type at regular intervals. However, all patients admitted to hospital for treatment experience similar problems to a greater or lesser extent.

Case study

Degenerative diseases are associated with the gradual development of symptoms, e.g. a decreased ability to undertake physical effort, breathlessness and pain. In its early stages the symptoms are not dissimilar to those of ageing, but the process occurs more rapidly than normal. The general practitioner is likely to be the first member of the health team to become involved with any individual, and he may well prescribe certain drugs and periods of rest before he decides to seek the assistance of specialists in the hospital in diagnosing the ailment.

The individual will be referred to the outpatient clinic in the local hospital for a consultation with the physician who will carry out a series of tests involving the measurement of a number of parameters, e.g. heart rate, electrocardiograph, peripheral blood pressure and respiration rate, both before and after exercise. On the basis of these objective measurements and subjective assessments of less readily measured parameters, a preliminary diagnosis can be made and a decision reached as to whether surgical intervention is required, either immediately or at some future date.

If surgery is required, the individual will be put on the appropriate waiting list and in due course will be admitted to hospital. After further tests, a preliminary minor operation will first be performed to allow more detailed measurements to be made of pressures and flows inside the heart itself; this involves passing flexible plastics catheters through peripheral arteries and recording with the use of suitable transducers the variation with time of pressure, and occasionally flow rate, in the various chambers of the heart.

The results of this investigation are combined with the other clinical data to confirm or contradict the preliminary diagnosis. Contradictory results would need to be reassessed before deciding on the best course of treatment, but we shall assume that a defective heart valve described as being 'incompetent' is confirmed as the most likely cause of the observed clinical symptoms: the final confirmation must await the opening of the heart in the same way that defects in any man-made machine can only be confirmed by disassembly.

Any open-heart operation is major since a machine must temporarily take over the job of pumping blood round the body, and, for technical reasons, the machine takes over the function of the lungs as well. A complete team is required consisting of three or four surgeons, anaesthetists, instrumentation operators, theatre sister, nurses and orderlies and a 'heart–lung machine'. Each member must be fully aware of the detailed procedures being carried out at every stage of the operation and the actions to be taken in any emergency.

Table 1 Some of the activities, staff and equipment that a patient undergoing heart surgery might meet. The list is intended merely to indicate the wide variety of items and is not intended to be comprehensive

Activity or location	Staff	Typical equipment
Home	general practitioner	e.c.g.; stethoscope
	health visitor	
	Social services	
Chemist	pharmacist	drugs
Admission	administration	hospital services
		bleepers, office equipment
E.C.G. laboratory	physician	e.c.g., recorders
Catheterisation	anaesthetist	ventilator, drugs
	cardiologist	cardiographs
	surgeon	pressure and flow instruments
	radiologist	X ray
	nurses	surgical instruments, catheters
Ward	ward staff	beds, 'hotel' equipment
	biochemical laboratory	analysers, microscopes
	orderlies	trolleys
Theatre	theatre staff	autoclave, swabs
	anaesthetist	defibrillator, ventilator
	surgeon	scalpels, clamps, 'repairkit'
	pump technician	heart–lung machine, plastics tube
	instrument technician	pressure and temperature equipment
Post-operative	intensive-care-unit staff	respirators, piped gases
Convalescence	physiotherapist	exercise machines
Return home	ambulance driver	ambulance, stretcher

The operation will last several hours since the chest must first be opened and the heart–lung machine primed and connected into the patient's circulation before his blood can be taken through the machine; only then can the heart itself be isolated and the first incision made into the appropriate chamber of the heart, whose regular beat is inhibited by applying a small constant current through the heart muscle which then 'fibrillates' in an irregular, unco-ordinated movement. The deformed valve can be excised and a replacement mechanical valve will be attached in its place by means of threads sewn through the rim of the valve and the tissue of the heart; the insertion of a single valve may take as long as an hour and two or even three valves may need to be replaced in severe cases. Once the incision in the wall is sewn up, the heart must be forced to beat again in a regular manner by turning off the small direct current and applying across the heart a large current for a short period of time which depolarises the heart muscle and allows the regular co-ordinated heart beat to reappear. The heart must then take over the circulation again before the heart–lung machine is disconnected and the operation completed by closing up the chest.

The patient will be taken from the operating theatre to the intensive-care unit which is equipped with a complex array of instruments to allow continuous monitoring and/or assistance of various bodily functions, e.g. respiration, and a staff trained specially in the care of severely ill patients. After two or three days the patient will return to the general ward, and, as he recovers from the operation will gradually become more independent until he is fit enough to be discharged from hospital and convalesce at home.

Table 1 summarises these activities and indicates the type of equipment which might be used to provide a complete service for the patient. The wide variety of electrical instruments gives rise to major problems of maintenance.[1] The 'hotel' equipment relates to the non-medical services required for the resident and non-resident staff and for the patients in the hospital including laundry, catering, transport, lifts, heating and air conditioning etc.

The special medical requirements do modify some hotel services, and they completely specify the requirements of operating theatres, treatment rooms and laboratories. A very wide variety of equipment is required and all services must be available 24 h/day, 365 days/year.

This example is intended only to illustrate the wide variety of equipment and facilities which a patient may require when receiving treatment for a particular medical condition. As the complexity of hospitals and their services has increased, so has their dependence on the engineer to maintain in proper working order the very costly set of equipment required to provide 'modern' medical care for the patient.

Alternative views of the hospital

The hospital is only a single component in a complex health-care system, and it is instructive to consider how a hospital appears to a number of different observers. Fig. 1 shows schematically how the health-care system in a community is seen by various individuals associated with the case study described above. Some components extend beyond the boundaries of the local community as indicated by the national and international boundaries. Subsystems of immediate concern to the observer appear in more detail than those having less effect on the particular activity being considered, even though the latter may in fact be equally complex entities; the patient's job may be with the local subsidiary of a multinational company, but this fact would be of minor interest to the individual when going to hospital.

The point which I wish to emphasise is that the hospital is seen quite differently by the various participants in this example. To the administrator and the DHSS, it is one of many such institutions which must provide the wide variety of services requested by the local consultants and general practitioners; to what extent they view the local population as being a vital subsystem of the hospital is not always clear. The patient notices all the sections of the hospital with which he comes into contact, but, in the normal course of events, he is unlikely to be aware of engineering, catering and laboratory staff.

The engineer should be aware of all aspects of the day-to-day running of the hospital, so that he plans and carries out his work with minimum inconvenience to all the other participants. He must apply his technical skills to the solution of real problems in an activity dominated by people to an even greater extent than in a factory: the 'process' deals with sick people, not inanimate objects, and solutions which ignore this fact will often fail, no matter how good they may be technically. In particular, if the engineer deals in any way with patients, he must be aware of the complex questions raised when one asks how medical practice can improve the health of the community.

When comparing alternative solutions to technical problems, from the choice of one's own personal transport to the design of a ship or a hospital, the simplest economic parameter is the immediate capital cost of the system. The danger is that this may lead to the choice of an expensive 'white elephant', and in many areas the total cost of buying, owning, operating and maintaining the system is a more satisfactory measure for comparing the true economic value of alternative solutions. This concept of 'through-life costs' is particularly important for major capital investment projects designed to be used for many years, and new hospitals certainly come into this category; however, it does not measure any of the subjective parameters, e.g. comfort and ease of operation or convenience of access which may in fact determine the ultimate choice.

Cost benefit analysis attempts to associate economic value to each of these parameters, so that they can be included in the overall costs, but the relative importance of each parameter and the individual nature of the aesthetic value can lead to ridiculous anomalies. (In the discussion on the 3rd London airport, a 13th century church would have been demolished if the Cublington site had been developed. The value placed on the church was equated to the amount for which the structure was insured against fire! Was this a reasonable value?) However, we are not interested in aesthetic problems here, but in the allocation of limited financial resources to the treatment of the sick. What facilities

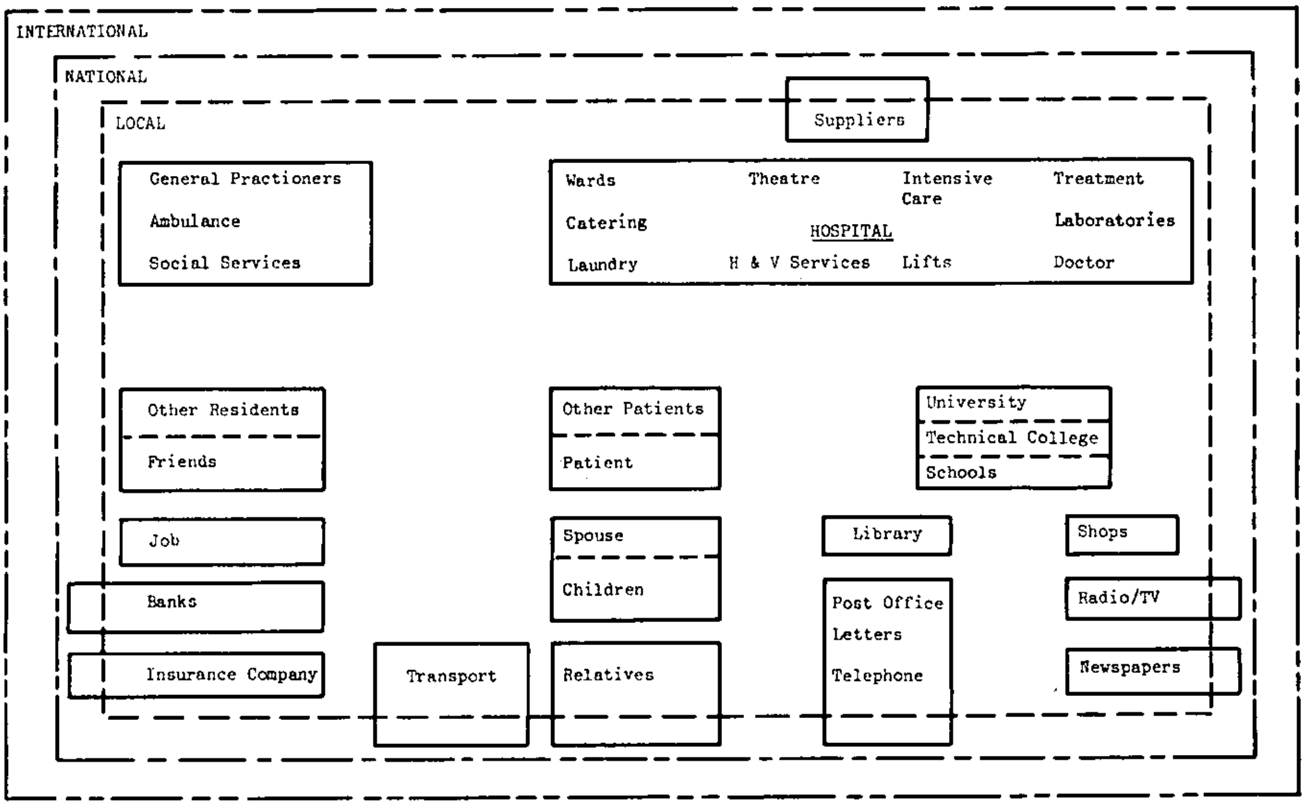
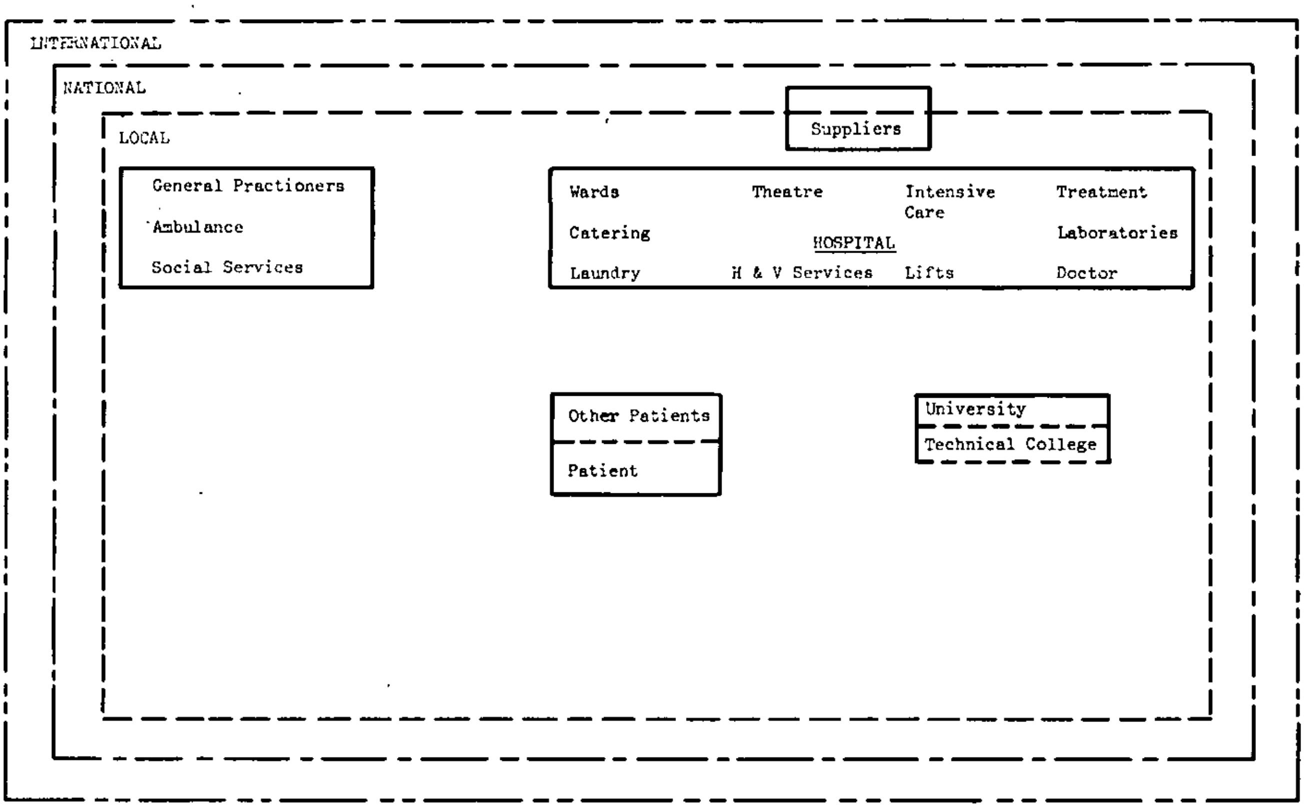
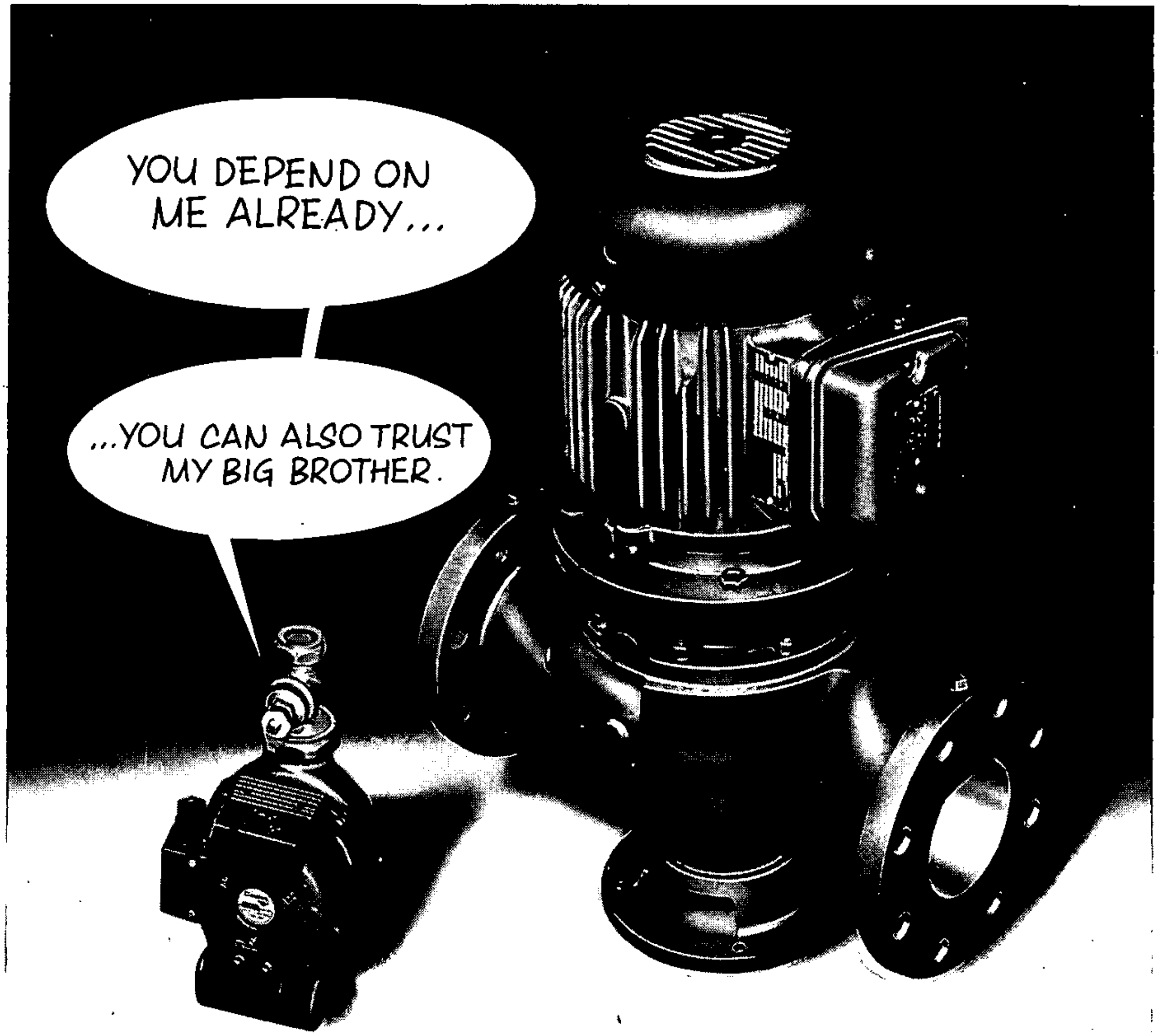


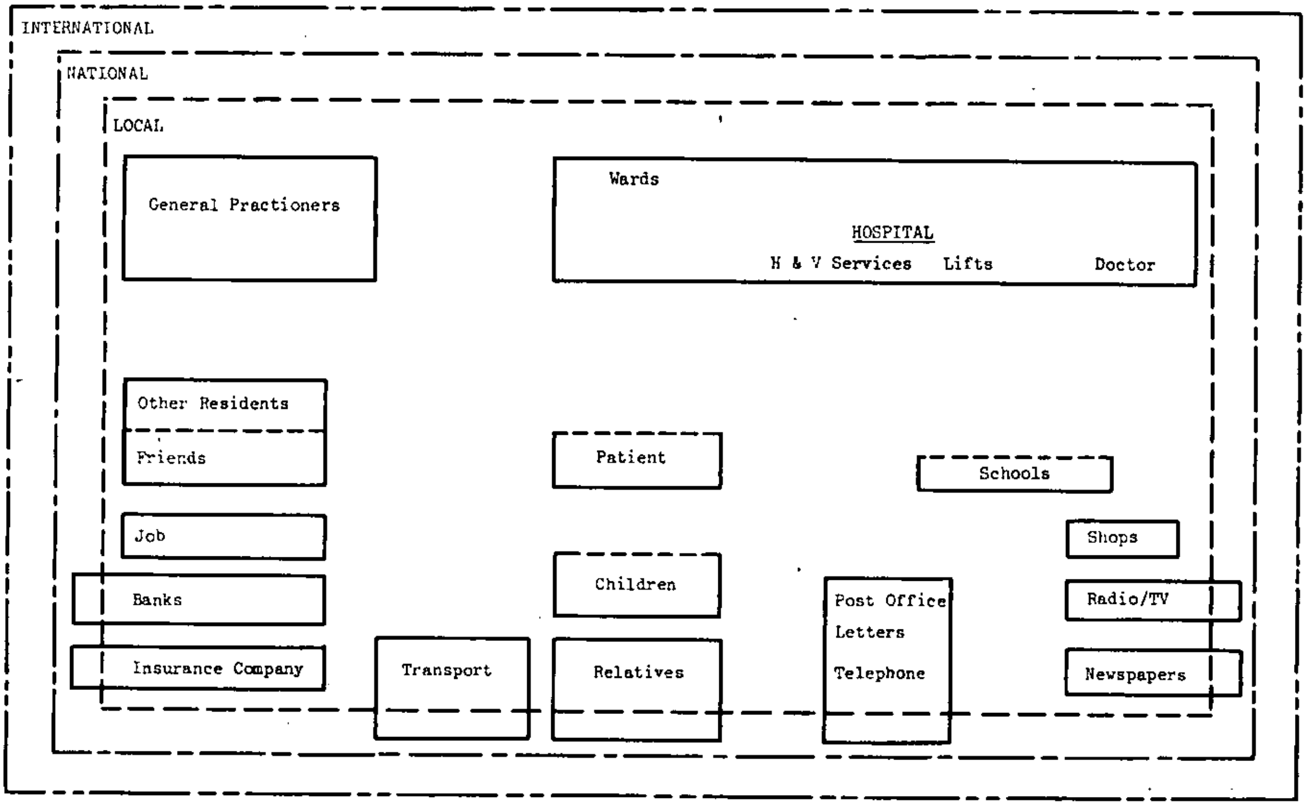
Fig. 1 Schematic representation of those parts of the local environment of concern to a patient entering hospital

a Total system being considered

b The system as it might be seen by the Health Service

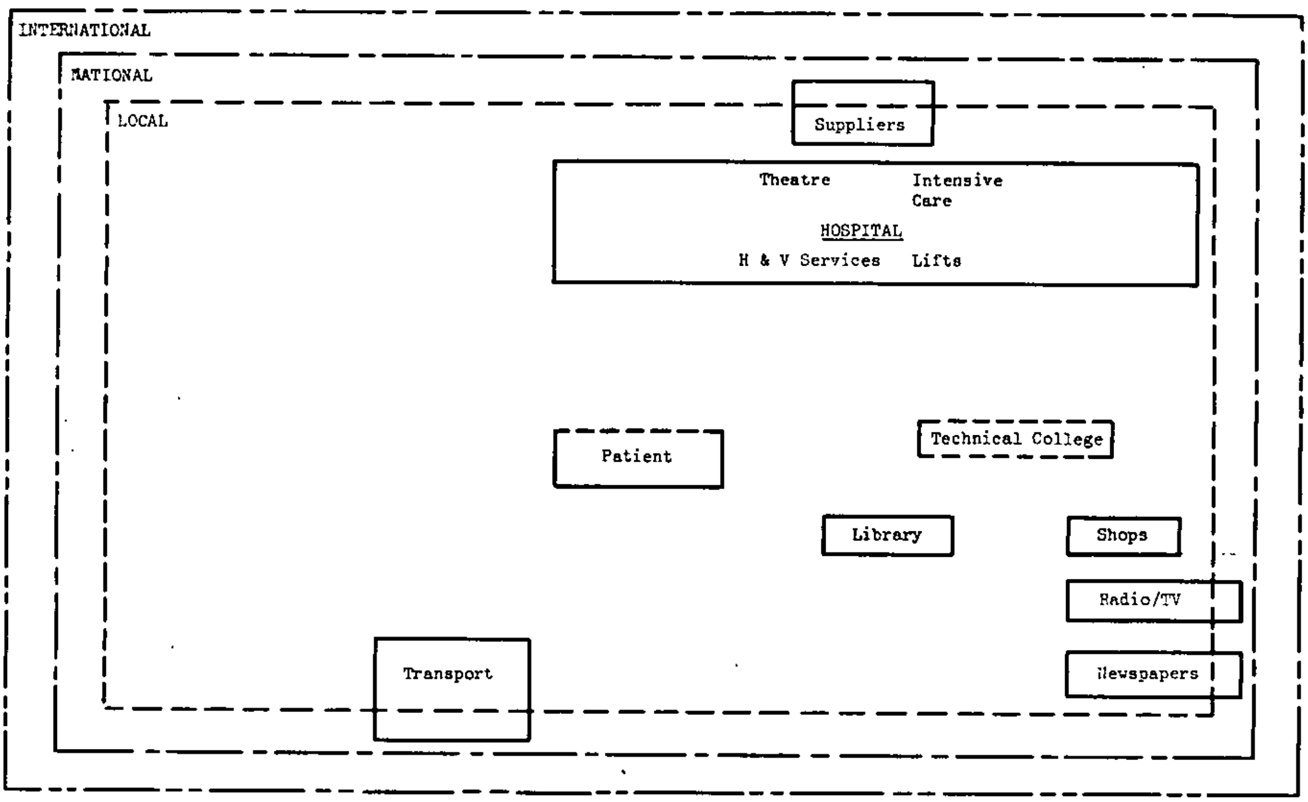



YOU DEPEND ON ME ALREADY...
...YOU CAN ALSO TRUST MY BIG BROTHER.



c **The system as it might be seen by patient's spouse**

d **The system as it might be seen by pump technician**



should be provided in a hospital? What preventive measures should be taken? In short, should the National Health Service and the population of this country be more concerned with the health of the many or the sickness of the few; and, the fundamental question, what do we mean by 'health'?

Health

The meaning of the word 'health' is less easy to define than 'hospital'. In an abstract sense it can be considered to imply 'absence of disease', but one is then faced with the even more difficult problem of defining disease. If adolescence and old age are considered to be diseases, presumably one cannot have a healthy adolescent or a healthy septuagenarian! Some cynics even go so far as to say that 'a healthy person is one who has not been properly examined!'

The Oxford English Dictionary defines health as 'soundness of body, that condition in which its functions are duly discharged' and gives the old English words 'Hale' and 'Hole' as being the roots from which health is derived. The World Health Organisation (WHO) has considered the problem and has produced its own definition (which certainly serves as the outer bound to any form of disease) as follows:

'Health is a state of complete physical, mental and social well being.'

Health, illness and disease

The first indication to an individual that he is suffering from some form of illness will be a number of symptoms, e.g. headaches, sickness, spots etc. Diagnosis is the process of determining the nature of the disease from which the individual is suffering. Preliminary observations of the patient will often supply many clues, but final confirmation frequently requires that parameters be measured either on the patient himself (e.g. temperature, pulse/pressure, respiration rate etc.) or on samples of fluids taken from the patient. The results of such measurements are quoted as values, frequently on a numerical scale, several of which may have to be compared to provide confirmation of the disease.

Let us consider a very simple case in which only a single parameter P is considered. If tests are carried out on a large number of healthy individuals, the distribution curve H (Fig. 2) will be obtained; a similar set of tests on individuals suffering from some particular disease might produce curve I. If the value of the parameter P were measured in a particular individual and had the value P_j as indicated, there would be an even chance of stating correctly whether he suffered from the given disease; for observed values of P greater than P_j, the individual is more likely to be ill, and conversely for P less than P_j he is more likely to be healthy.

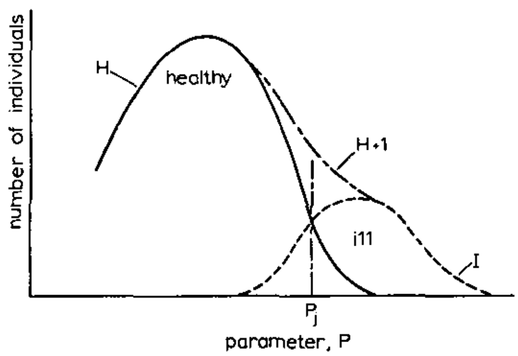


Fig. 2 Distribution curves for parameter *P* as measured in a given population of healthy and ill individuals

A similar type of uncertainty arises in engineering practice with the fatigue life of structure or the reliability of components; e.g. if the question were asked whether an individual component will be operating satisfactorily after a specified time, one can only quote a probability derived from tests on a large number of similar components operating under similar conditions. Methods are certainly available for estimating the overall reliability of complex engineering systems from data on the reliability of individual components, but this type of analysis usually refers to the black-and-white situation of elements being either functional or broken.

The medical definition of health and illness involves a continuous spectrum of states from one extreme of well-being to the other of imminent death, with so many unmeasurable and dynamic variables that it is impossible to define precisely the state of the individual at any given time. The need to classify illness in terms of a limited number of 'diseases' follows as a direct consequence. The causes may be similar (e.g. a virus) or the effects may be related (e.g. rheumatism). There is, of course, a continuing refinement of the classification as more sophisticated instruments become available and more detailed knowledge is acquired. It is interesting to note that more than 70 separate areas of medical specialisation are now recognised, a number which has more than doubled in the past 15 years as the distinction between diseases has become better defined with the advent of new and improved measurement techniques.

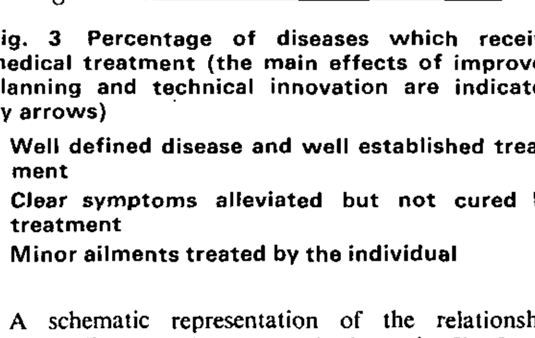


Fig. 3 Percentage of diseases which receive medical treatment (the main effects of improved planning and technical innovation are indicated by arrows)

a **Well defined disease and well established treatment**

b **Clear symptoms alleviated but not cured by treatment**

c **Minor ailments treated by the individual**

A schematic representation of the relationship between disease and treatment is shown in Fig. 3 as a form of bar chart. The vertical scale indicates the percentage of a particular disease which receives medical treatment while the individual diseases or illnesses are identified along the horizontal axis. The diseases are classified into three classes:

(*a*) those where the disease is well defined and an established form of medical treatment has been shown to be effective in assisting the majority of patients to overcome the disease

(*b*) those where there are clearly observed symptoms, some of which can be relieved by medical treatment, but where the underlying cause of the disease cannot be treated

(*c*) those which can be satisfactorily overcome by self treatment, either because they are of a minor nature (e.g. dietary advice or a grazed knee), or because recurrent attacks indicate that such treatment is the most satisfactory (e.g. some forms of migraine and asthma).

There are also illnesses that may only become recognised as specific diseases after detailed examination of existing data and the addition of extra data, often following the introduction of new measurement techniques. These diseases are included in (*c*).

The horizontal axis can be considered as representing the 'state of health'. Only an individual suffering from none of these diseases would be considered completely 'healthy' according to the World Health Organisation definition. However, he would not normally be considered ill if he suffered from one or more of the diseases in (*c*), so that the right side of the diagram represents generally healthy people tolerating the normal aches and pains of everyday life.

At the opposite end of the scale, a person suffering from one or more diseases in (*a*) would probably be considered to be 'ill', and it would be generally agreed that all patients in this category should receive the medical care required to improve their state of health.

Potential conflicts arise with diseases in (*b*) where there may be considerable demand for medical care from both doctors and their patients despite uncertainty about the need for and the efficacy of the treatment. When this treatment contributes to the alleviation of pain with no significant danger to the patient it can be fully justified. However, an appreciable proportion of such treatment may contribute only towards the almost religious idea of 'faith healing' between doctor and patient, since they both feel more mutual satisfaction when a cure is associated with some form of treatment rather than with natural causes; the worst cases may actually lead to an incidence of disease, since no treatment is without risk. A specific example is the use of implanted pacemakers to trigger the electrical activity of the heart; natural diseases very rarely damage the trigger mechanism of the heart without simultaneously causing other fatal effects whereas the surgeon's scalpel can relatively easily sever the conducting fibres while performing other surgery on the heart. The number of 'iatrogenic' diseases is regrettably ever increasing and they are most commonly related to the side effects of drug treatments.

Supply and demand

Public demand for medical treatment always tends to exceed the available resources, and publicity combined with changing public attitudes encourages the vast potential demand for treatment, especially for chronic conditions associated with degenerative processes. Technical advances can transfer diseases from the unproven class (*b*) to an accepted treatment in (*a*), but at the same time the total demand for medical care may well increase, owing to a misplaced desire to use the new technique on an experimental basis for treating a range of other conditions in class (*b*).

The overall objective of a national health-care system should be to allocate scarce resources, so that priority is given to the treatment of diseases in class (*a*) over those in class (*b*). The uncertainty inherent in defining disease, let alone the perpetually changing boundaries between different classes of disease, requires a continuing process of data collection and assessment if the best use is to be made of health-care resources.

This raises the critical, but sensitive problem of evaluation. One of the few areas in medicine where extensive clinical trials are regularly organised is in the assessment of new drugs, where complex statistical techniques are used to establish the efficacy of a given drug against a known disease by comparing carefully, over an extended period of time, the results when the drug, or a placebo, are administered in a random manner to groups of patients. Comparison with alternative methods of treatment can sometimes show that complex methods of treatment have no advantage over very conservative methods, but such 'unwanted' results are frequently discounted by appeal to the inherent uncertainties in the experimental data.

For example, a comparative study of heart attacks in which half the patients were treated at home, while the other half were admitted to an intensive-care unit in a hospital demonstrated that there was no significant difference between the number of survivors; the peace and familiarity of the home environment with fewer technical aids was as effective as the full range of diagnostic and therapeutic instruments in an unfamiliar and potentially stressful environment. Yet, given such evidence, how many hospitals would dispense with their intensive-care units?

In Britain, the individual doctor is still at liberty to prescribe drugs which have not been fully tested; obviously trials of any new treatment must be carried out with human subjects, but it is important that such subjects be warned beforehand that the treatment or drug is not fully tested and that there may be unpredictable side effects. Even when drugs have been tested and approved it is always possible that certain untested combinations of drugs may produce undesirable side effects; the dangers of taking alcohol in combination with certain stimulants is now well known.

Artificial components have been used in orthopaedic surgery for many years, but the plates and screws used to hold pieces of bone together evolved as a result of discussions between the surgeon and his technicians; at no time were the devices designed and tested in the engineering sense. As more complex active components were considered as replacements for moving joints in the body, the need to involve engineers in the design became much more widely accepted; and the current worldwide interest in artificial knee joints is taking place with full collaboration between individual doctors and engineers. However, a major danger lies in the proliferation of different designs, amounting to some 150 at a recent count, when the assessment of different diseases of the knee would indicate a need for perhaps half a dozen different types.

In order to justify a particular design, there is a great temptation for the surgeon to use it for every possible patient regardless of the particular disease or the real suitability of the design for the individual patient. In this way clinical experience is rapidly acquired, but, if defects appear as a result of extended use, and one is interested in a useful life of at least ten years, rapid and premature 'progress' can lead to the serious problems of revising the original procedure, which is often much more difficult than starting from the beginning. The need to use an adequate, and perhaps standardised, method for assessing orthopaedic and other implants is essential if we are to avoid large numbers of patients who are put at risk by being treated in a way that suits the surgeons. Perhaps we should start by banning the practice of naming components after the originator.

Medicine and engineering maintenance

In the past century, medical science in common with engineering science has made great progress in understanding the behaviour of the materials and systems with which each is concerned. However, it must be appreciated that whereas engineering is concerned with the design and maintenance of man-made equipment, the medical profession is concerned only with the behaviour of an existing system.

With the gradual elimination of many infectious diseases, life expectancy in developed countries increased significantly at first, but it now appears to have reached a plateau and has even decreased slightly in the United States. Thus improved medical care, like engineering maintenance, can increase the likelihood that the individual will survive for as long as the major components remain functional, but it cannot extend the potential life span of the system. For example, it has been estimated that if life expectancy increased to 100 years, over half the population would suffer fracture of the femur and require surgical treatment. This is in contrast to engineering systems where the designer can extend the potential life of a machine by increasing the fatigue life of each component.

But we must consider now the long-term implications of our present actions and plans. The world's resources are simply not adequate to provide a general application of the advanced technologies of the developed western world, and we must consider whether a continuing differential should be maintained between ourselves and developing countries to allow us to continue further on the path of energy and material-intensive technology.

At the same time, in both medicine and engineering, there is a long time lag between the first practical application of a technological innovation and the time when its secondary effects are seen to be seriously adverse. Corrections can readily be made at the early stages of development but they can be very difficult to make by the time the full implications are understood by the public.

As engineers associated with medicine in the treatment of disease, we have a duty both to our profession and to the public at large to be aware of these problems. We may not be in a position where we can directly influence policy makers, but we must each try to teach ourselves and others with whom we interact to think about the place of engineering and medicine in the society which we are now forming for our descendants.

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2 DADDARIO, E. Q.: 'Technology and the democratic dilemma', *Mech. Eng.*, 1975, **97**, pp. 20-22

3 ILLICH, I.: 'Medical Nemesis' (Calder & Boyars, 1975)

4 'Prospect on health' (Office of Health Economics, 1971, 37)

HE Product news

Welding and cutting set

The Portapak portable welding and cutting set uses aluminium oxygen and acetylene cylinders, which, when full, will give up to 20 h of operating time depending on the application. The cylinders are supplied on a long-term deposit system incorporated into the purchase price. The unit uses the Saffire FNSO blowpipe, which has a gun-drilled shank that can be used for cutting, welding or attaching a range of welding nozzles. It is possible to fusion weld up to 8 mm-thick sheet and cut up to 20 mm-thick plate.

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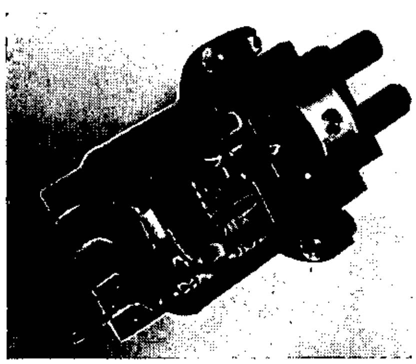

separate readout instrument. It has an accuracy of within ±1% over a range of flow rates from 1 drop per 1·5 s to 20 l/min. Linearity is within ±1%, and the repeatability is better than 0·5%. The range of instruments can be calibrated in litres per second, per minute, per hour and in imperial units.

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Product news

of the printed-circuit board minimises the loss of sunlight. With the module in constant use the temperature range is from −50 to +75 deg C.

Photain Controls Ltd., Unit 18, Hangar 3, The Aerodrome, Ford, Sussex

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Andrew Stephens (1947) Co., Medical Electronics, 41 Dickson Road, Blackpool

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Channel Electronics (Sussex) Ltd., Cradle Hill Industrial Estate, Seaford, Sussex BN25 3JE

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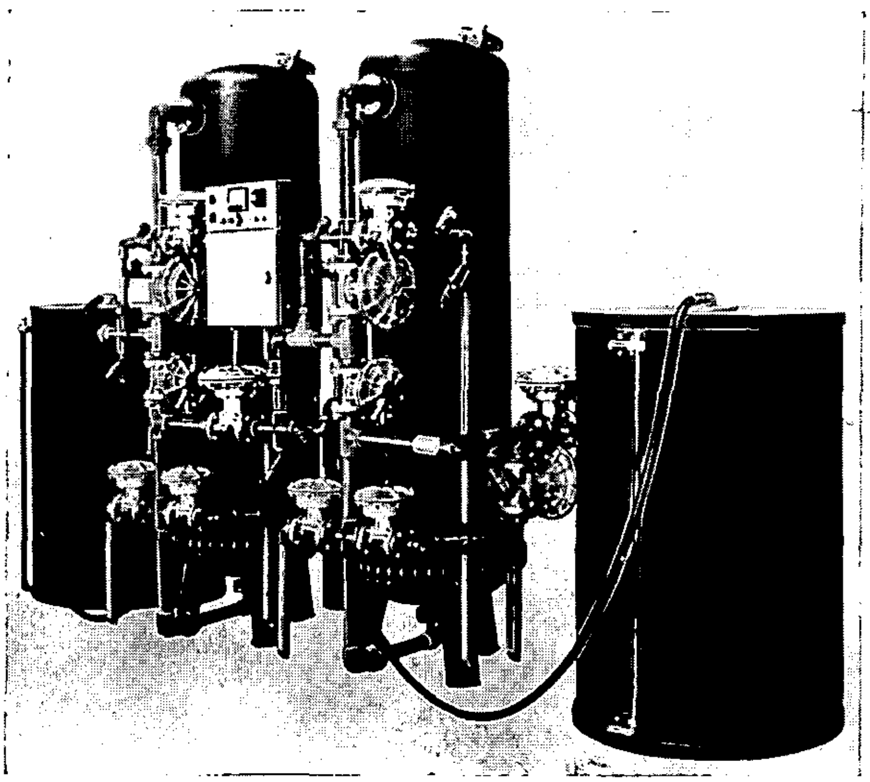

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