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CONTROLLED CLIMATE CHAMBERS
FOR BUILDING RESEARCH

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November 1980

1. SUMMARY

This describes a set of four controlled climate chambers recently commissioned at the Building Research Association of N.Z. station at Judgeford, Wellington.

The chambers are of walk-in size, arranged in two pairs, and each dynamically controlled to its own selected sequence of temperature and humidity. It is intended that natural climate exposures will be simulated. The range of conditions attainable is wider than those encountered in this country.

2. FUNCTION

Facilities such as this tend to generate new demands once they exist, but there were 3 basic objectives in mind when the chambers were developed:-

- to test and demonstrate adequate methods of moisture control within building structures
- to investigate whether, and how much, moisture movements may undermine the effectiveness of thermal insulating systems in buildings
- to permit preliminary trials of building materials or components for export to foreign climates, e.g. for evaluating distortions, etc.

There are of course a number of existing controlled climate chambers in use in New Zealand, but most of these are not capable of the above tasks because they are able to function only at constant conditions, or at best in a series of steps. One major exception to this are the series of chambers at Plant Physiology Division, DSIR, Palmerston North. There are also packaged chambers available commercially, which have at leat the potential for variable control. However there were at least 4 major reasons for developing a new set of chambers:-

- Control stability - many of the intended uses of the chambers involve the measurement of surface heat flux at surfaces, and this fluctuates wildly if there is any sort of on-off control anywhere in the system. Stepless control was therefore essential.
- Pair application - in contrast to most existing chambers which control conditions within a chamber, we required to control (separate) conditions across a test wall, roof, or floor.

- Duration - some tests have to run continuously for many months. It is not feasible to tie up borrowed equipment for such long periods.
- Data-taking - setting up chamber conditions is only part of the exercise. There is also a need for continuous and extensive data taking and processing on the response of test structures. In some cases, the course of future testing may be varied according to previous response. This indicates that the testing should take place where the data processing and test supervision is done.

3. DESIGN CRITERIA

With the above conditions in mind, the following design criteria were set:-

Chambers

A minimum of four chambers were required, arranged in two pairs. One pair was to accommodate wall samples, and the other roof or floor samples. The orientation affects heat, air, and moisture movements within the test structure. So that realistic construction details and panels or components could be tested, the chambers would need to accommodate samples of $1\frac{1}{2}$-$2\frac{1}{2}$m in size. There would have to be walk-in access for attaching sensors and to permit inspection.

Conditions to be generated

Temperature Range	-10°C to 80°C
Dewpoint Range	-15°C to 30°C
Maximum point-to-point variation within chamber	½°C
Rate of change	30°C/h

Operating efficiency was to be as high as practical

All processes essentially stepless.

Control

All chambers to be independently controllable to any condition within the above range, and dynamically variable.

Temperature control error	1°C
Humidity control error	2% RH

The chamber conditions were to be computer controllable (or equivalent such as punched tape).

Although specific targets were not set, it was important that the chambers be able to respond to fairly large rates of change. To achieve this depends mainly on the design of the chambers and plant, rather than of the controls.

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Operation	All parts of the system were to be capable of continuous operation, unattended, for long periods.

5. DESCRIPTION OF SYSTEM

The system installed is illustrated in Figs I and 2. It has a 5 kW, air-cooled refrigeration compressor (R503) which chills a 300 litre tank of 65% ethylene glycol and water, to -20° C. The glycol fluid chills a closed circuit chilled air duct to between -10 and -20° C, continuously and without control. This duct is treated as a chilled air "sink" by the 4 chambers, and some of the chilled air is bypassed into the chambers, If either cooling or dehumidification is required, chilled air is admitted. Heating or humidification is generated locally within the chambers, each of which has its own internal circulating fan and mixing duct.

The chambers were made from lightweight, plywood faced, polystyrene panels, into 2m cubes, and each chamber is on wheels (with tilt trim adjustment) to provide easy erection and inspection of test structures. Doors are of the same material, double sealed, and all can be opened from inside, without tools, in any foreseeable circumstance including breakage of parts of the door latch.

The control is effected by a standard microcomputer data logger, which has been programmed to run as an 8-channel industrial P.I.D. 3-term controller. The controller can be set to maintain any selected (fixed) settings from a control keyboard, or to varying settings by reading punched paper tape. The 5V output control signals from the computer are isolated by optical coupling devices, which switch 230V or lower A.C. loads via triac solid state switches.

There is provision for manual selection switches to be plugged into the control panels on each chamber, in the event of computer failure or a requirement for fixed-power action on the chamber.

6. COMMISSIONING

In contrast to many refrigeration and airconditioning installations the commissioning of this plant was able to be carried out thoroughly and logically, and recorded fully. In fact there are several quite novel features in this plant, and careful measurement was needed to show exactly how these novel features had worked out.

The refrigeration capacity was measured as in Fig. 3. The various kinks in this curve are believed to result from particular plant features, such as a suction pressure regulating valve for current-limiting purposes.

Of equal interest for plant designers especially of small plants, is the information relating to the various capacity losses due to pumps, fans, and insulation losses. Even with well insulated ducts (100mm polyurethane foam in this case), losses can be a dominant part of the load.

The performance of the glycol reconcentrator was an important part of the commissioning. An item of major interest arising out of this was the degree to which temperature stratification was able to undermine heat exchanger performance in the liquid-liquid heat exchanger, Fig. 4. In many other liquid-liquid exchangers the fluid velocity on the secondary side is also low or zero, and similar results might occur there.

One of the greatest difficulties occurred in the liquid-air heat exchanger where the glycol fluid chills the air stream. Initially *this was a standard spray unit with corrugated spray eliminators.* Normally spray units have very high heat exchange capacity, but in the case of these glycol sprays there is very little evaporation. The heat exchange is almost wholly sensible, and the capacity is quite small. Any design using glycol sprays will have to be engineered carefully to ensure that there is enough heat transfer capacity, and it may not be easy. In this plant the heat transfer capacity was not high enough, see Fig 5.

The second difficulty with glycol sprays is that the spray carry-over requirements are much more stringent than with water sprays. Whilst some water sprays some carry-over is acceptable (since one droplet carried over is likely to evaporate before another arrives) this does not happen with glycol. Any *droplets carried over will stay there until joined by others.* Eventually enough liquid will accumulate to cause trouble, and occasional washdown is essential. Provision for washdown and drainage must be made.

Subsequent to these two difficulties, the liquid/air chiller section was modified to a packed-plate form. Glycol fluid is trickled down vertical plates, so that as little splash as possible was produced. Although better, and workable, even this version will need further improvement.

The controls have been very successful. Where limitations in control have occurred, this has resulted either from sensor defects, or from encountering plant capacity limit. The control programme looks at the conditions in each chamber by turn, calculating any corrective action. It gets around each chamber between 1 and 4 times per second, depending on the number of chambers in use and the control conditions. A standard 3-term control (proportional + integral + derivative) is used. On switch-on, default values of the controller parameters (P, I & D) are set up, and these can be altered subsequently if desired. Any chamber can be "on" or "off" control, and can be either fixed or ramped, all chambers independently. The ramping is achieved by specifying a future level, and the time by which it is to be reached. This ensures that the required control is forced to converge to the correct range, even if it somehow gets out of line or there are calculating rounding errors. Fig. 6 illustrates the results of reproducing 2 days of an actual weather record, plus some test conditions.

The implementation of computer signals at 5 V.D.C. levels, into plant actuation including 230 V.A.C. mains switching, is done as follows. Firstly, electrical isolation is established by an opto isolator, and then the isolated signal from this is used to switch a triac which carries the mains power. If switching is relatively infrequent, triac switching is sufficient, but if radio-frequency noise suppression is required, zero-crossing detectors are readily available to control switching of the triacs to occur only at instants when the mains voltage is momentarily at zero.

LESSONS

Lessons from this installation, which can be taken by designers of plant using any similar methods, include the following:-

Digital control of plant by micro computer can be highly successful.

Glycol sprays for chilling air will often have much lower heat transfer capability than water sprays (because there may be little evaporation). It may be necessary to design some glycol spray systems for 100% sensible heat transfer, and this may not be easy. - See Fig. 5.

Glycol sprays have much lower tolerance to spray carry-over or splash than do water sprays. There should always be provision for periodic washdown.

Twoport mixing control of air in ducted circuits (the equivalent to two-way valve mixing control in water circuits) can be very successful, giving smooth and linear control, but is dependent on a good quality shut-off in the damper.

Standing losses in small systems can be surprisingly large, and should be carefully assessed in design.

BIBLIOGRAPHY

Descriptions of other controlled climate test facilities can be found in the following:-

1. Climate Laboratory. Palmerston North, Dept. of Scientific and Industrial Research (New Zealand) Plant Physiology Division. 1974

2. *Burch D.M., Peavy B.A., Powell F.J. Experimental validation of the NBS load and indoor temperature prediction model. ASHRAE Transactions 80 Part 2 291-310 1974.

3. *Mitalas G. An experimental check on the weighting factor method of calculating room cooling load. DBR Research Paper 453. National Research Council of Canada. Ottawa 1973.

* More complete descriptions of these facilities are still being sought.

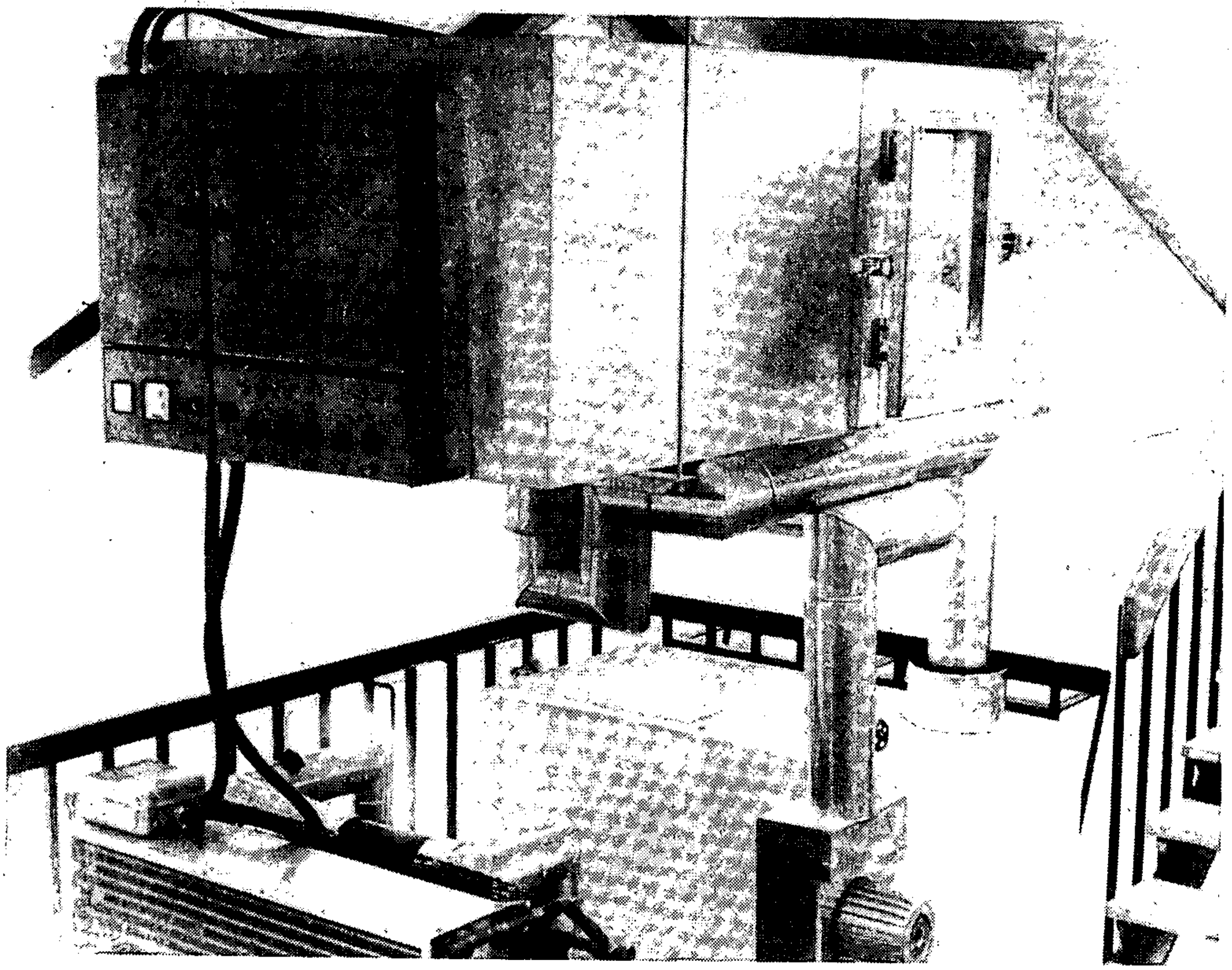
Humidification - boiling type, electrically heated, with time-proportional control (period 16s) supplied by microcomputer. Standby thermostat to hold water to 80-90°C in readiness.
Permanent level-controlled water supply of collected rainwater.

Manual over-ride - available at all stages. All dampers can be manually positioned by plug-in drive switch, heaters can be forced to any desired level by plug-in selector switch.

Indication - Most functions indicated by pilot lamp or L.E.D.
Status control reports can be obtained giving current set points, achieved values, proportional and integrated errors, plant actuator position and heating level, at time of report.

APPENDIX: SCHEDULE OF EQUIPMENT

Refrigeration:	Compressor, R503, 5kW Crankcase heater Suction pressure limit control C.O.P. - 2.0 - 2.4 as measured at -20°C evaporating temperature Condensor, Air cooled, twin fan Evaporator, 300 litre, 65% ethylene glycol tank.
Cooling Circulating Pump:	Perfecta NCP6, waxfilled.
Glycol reconcentrator:	Boiling type, controlled to 115°C, 4.5 kW Laboratory glass heat exchangers for sensible heat interchange. Flow rate 5-7 g/s.
Fan:	Woods 15J, 1440 rpm
Ducting:	Two skin, 100mm in-situ foamed polyurethane between two metal skins. Flexible connectors, fibreglass insulated spiral-flex aluminium, with polythene outer skin.
Chambers:	Plywood faced insulated polystyrene foam panels, 100mm thick. Mounted on wheels for easy sample access. Tilt adjustments available. Doors, walk-in size, double edge sealed, seals having 10mm tolerance. Door latches openable unaided without tools from inside.
Controls:	Controller PACIFIC microcomputer data-logger reprogrammed as 8 channel industrial P.I.D. controller, accepting keyboard or (paper tape) serial commands. Temperature sensors - National semiconductor transducers (10mV/c) LM 3991 Humidity sensors - Wet-bulb psychrometer, fan operated, with 10-junction Cu/Con thermopile wet bulb depression sensing. Chilled air control - GEC iris shutter dampers, positioned by Satchwell actuator motors. Heating - Wire wound electrical heaters, arranged in groups to form a binary power sequence (from 16W to 2000W) sail switch overheat protection.



VIEW OF REFRIGERATION COMPRESSOR, GLYCOL TANK, AND SPRAY CHAMBER

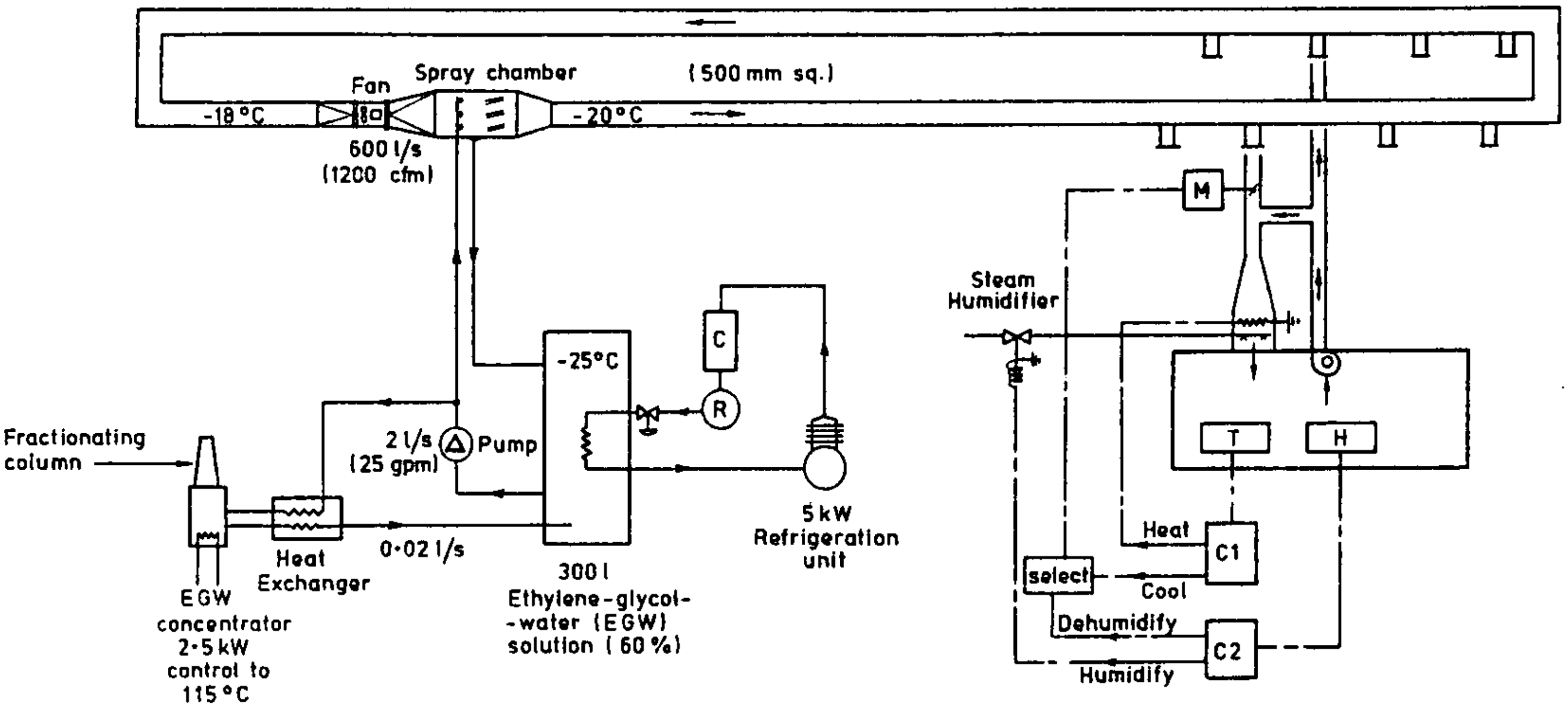
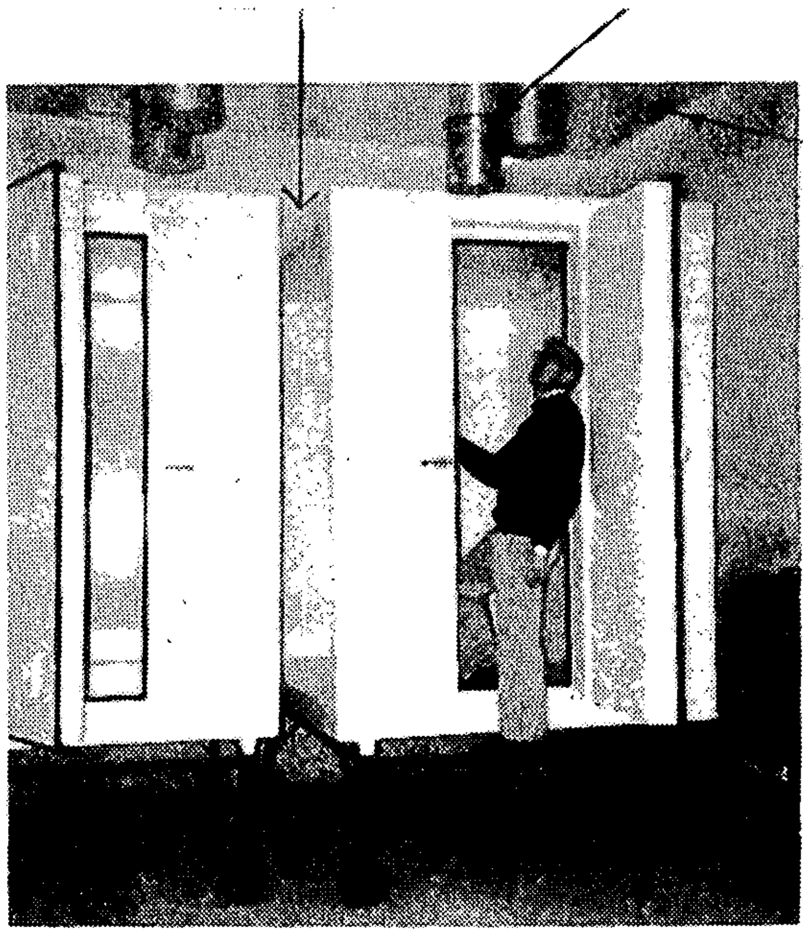


FIG 1: GENERAL LAYOUT



VIEW OF TWO OF THE FOUR CONTROLLED CHAMBERS, WITH CHILLED AIR DUCT ABOVE

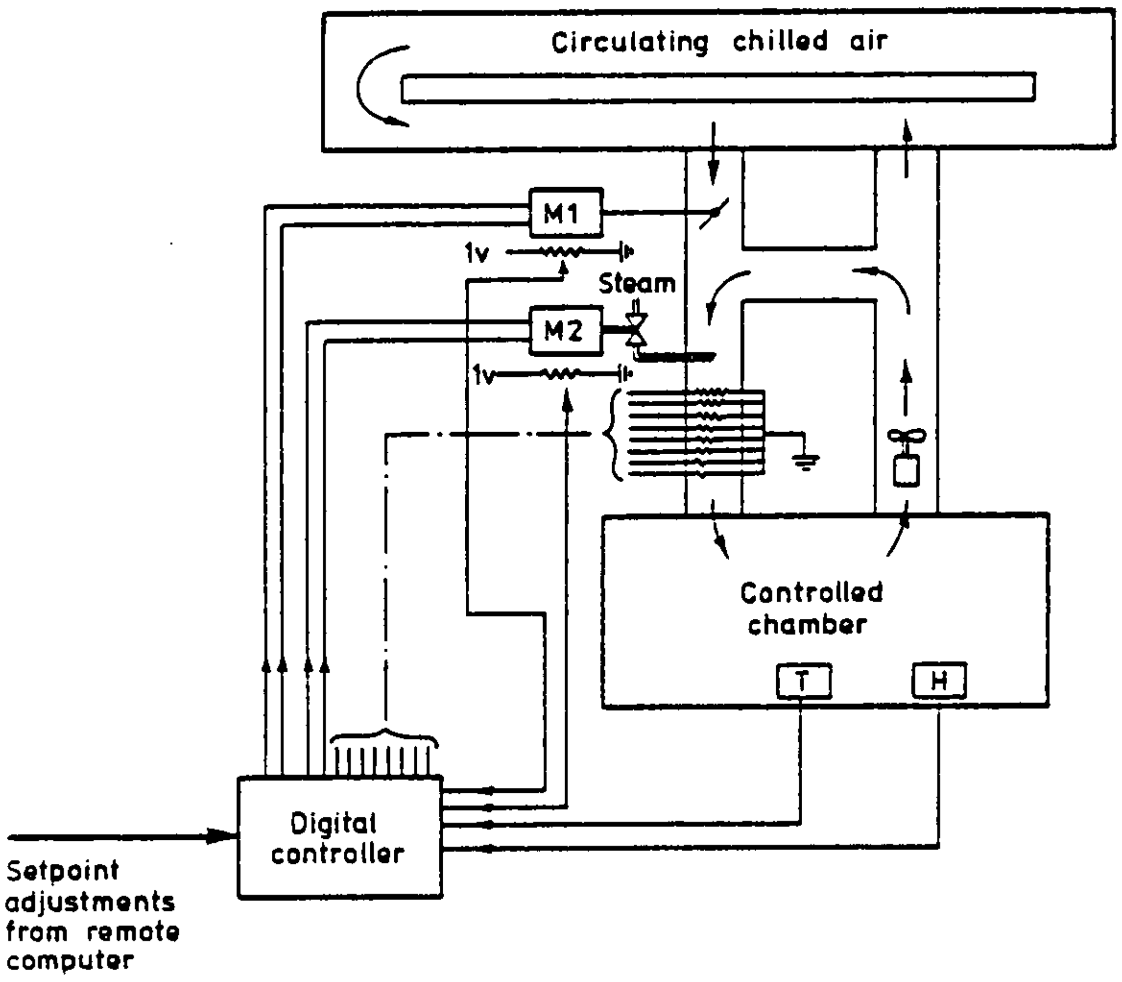


FIG 2: SECONDARY CONTROL SYSTEM

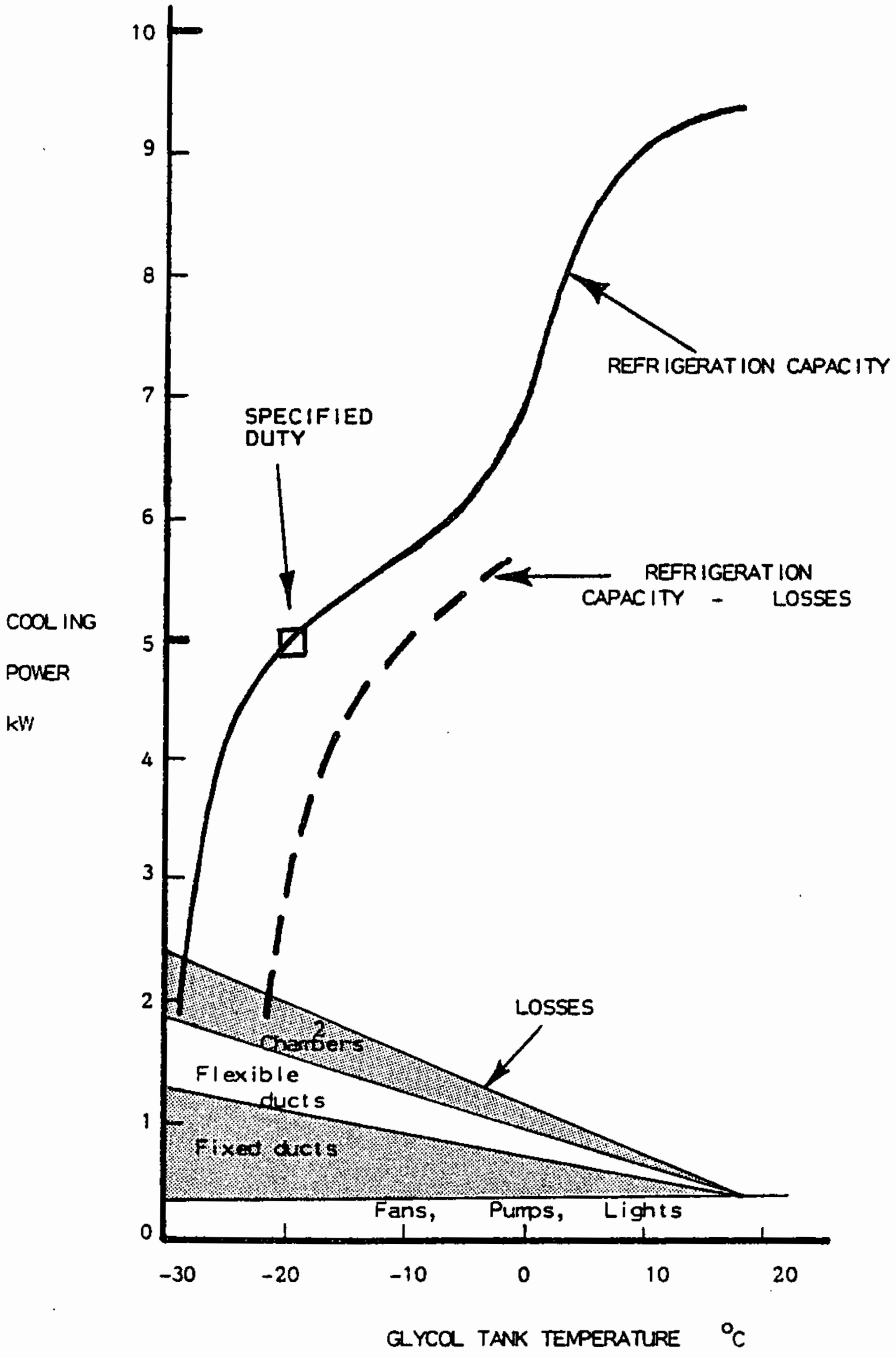


FIGURE 3 : COOLING POWER & LOSSES IN THE PRIMARY CHILLED AIR SYSTEM

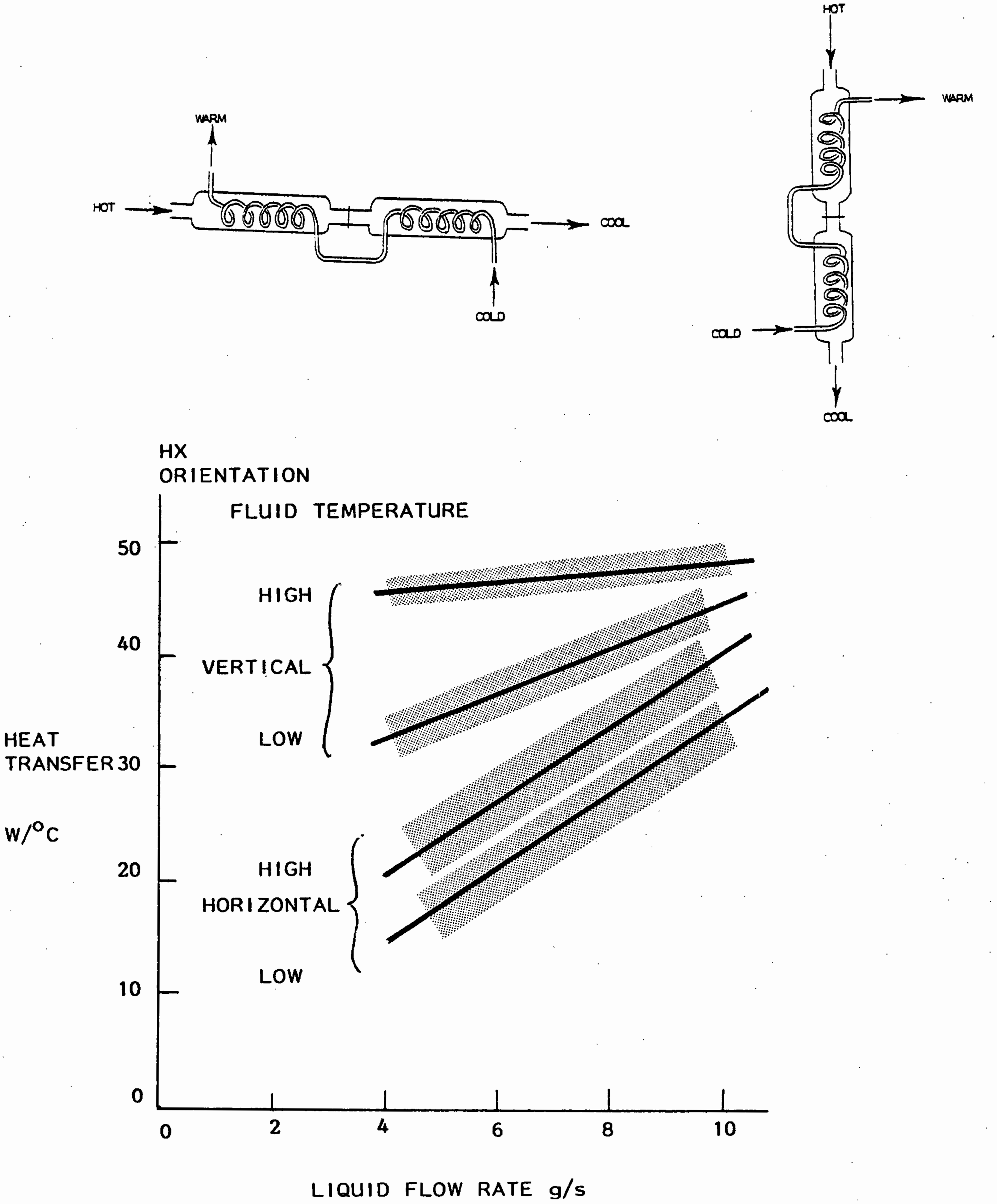


FIGURE 4: <u>EFFECT OF ORIENTATION ON MEASURED HEAT TRANSFER</u>
<u>LIQUID/LIQUID HEAT EXCHANGER</u>
resulting from temperature stratification

HEAT TRANSFER per litre of bed W/l°C

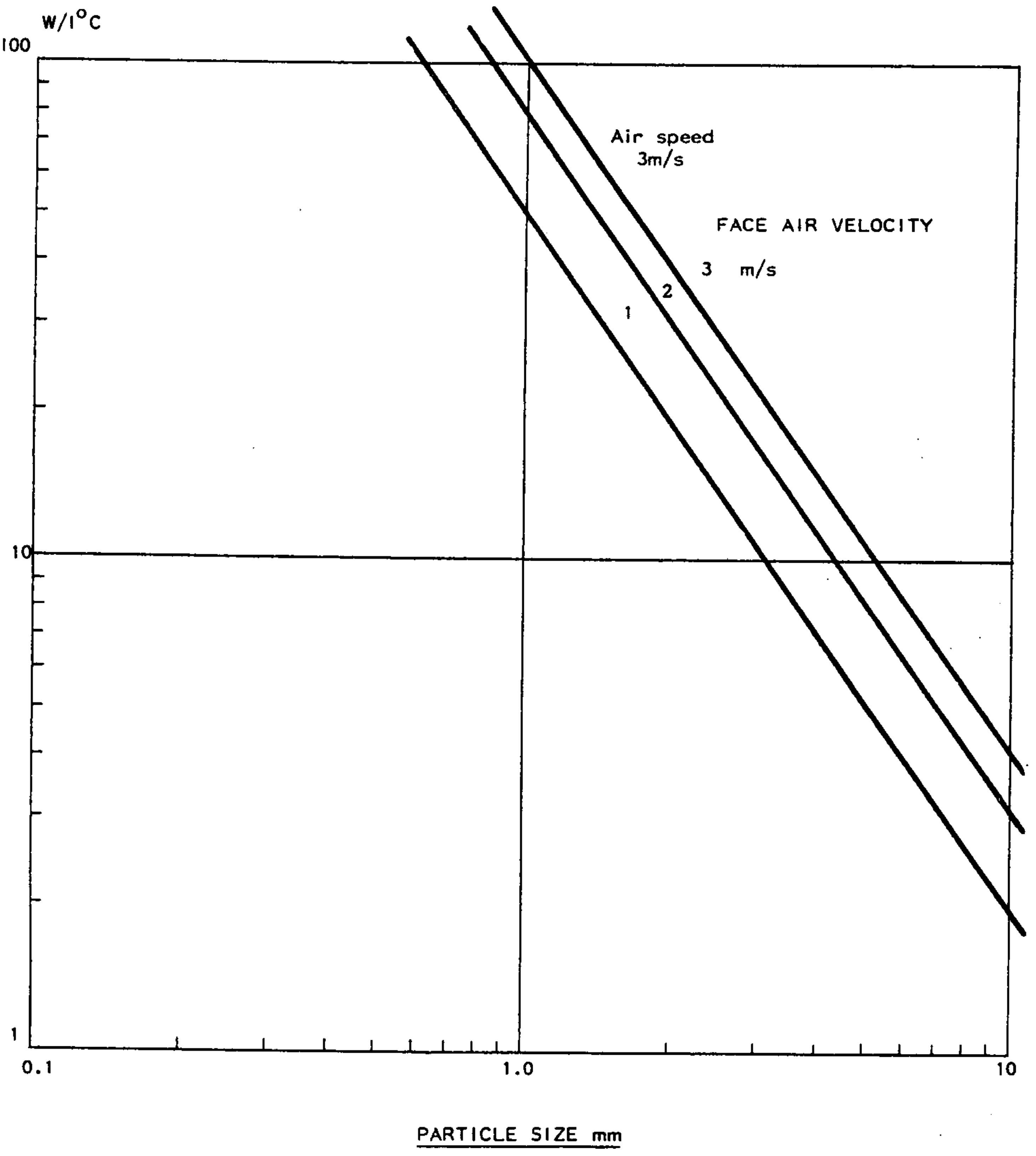
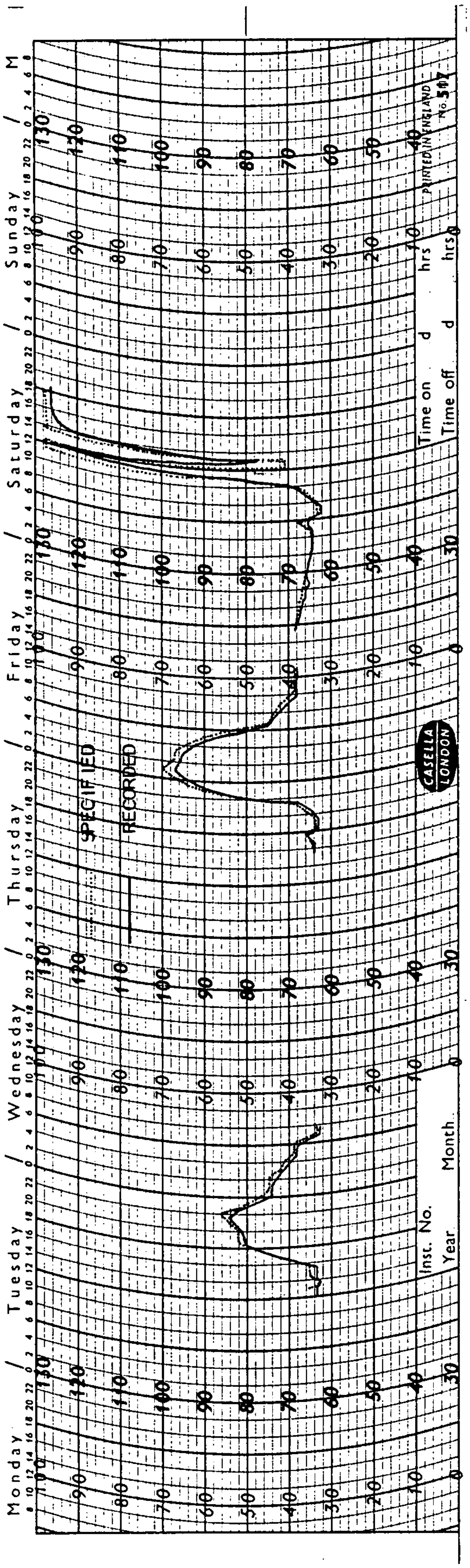


FIGURE: 5
SENSIBLE HEAT TRANSFER CAPACITY OF A PACKED BED
(OR NON-EVAPORATING SPRAY)



SERIES

FIGURE 6: EXAMPLE OF CHAMBER PERFORMANCE UNDER VARYING CONDITIONS