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THE APPLICATION OF CONDENSING BOILERS TO COMMERCIAL PREMISES

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The number of commercial condensing boiler installations in Britain has been growing steadily since these boilers were first introduced from the Continent in 1983, where significant numbers of installations have been made, particularly in France and the Netherlands. The design requirements for commercial condensing boilers are now well understood and the boilers have the potential to achieve very high efficiencies. Various installation and heating layouts have been proposed to maximise the boiler efficiency, especially in new installations. The relative advantages and costs are shown along with more detailed analysis from case studies of existing installations. These include new, retrofit and mixed installations, covering different boiler designs, building type and heating circuit design. The paper concludes by examining specific developments which may occur in the future and which should widen the options of commercial condensing boilers to building services engineers.

INTRODUCTION

At the British Gas Watson House Research Station a variety of commercial boilers have been tested on a purpose designed test rig to determine their full and part load efficiencies under operating conditions. These tests have shown that there are three distinct classifications of boiler. For simplicity, these can be called "traditional", "high efficiency" and "condensing". Figure 1 shows the typical part load operating efficiencies for these different types of boiler.

The current high efficiency boilers are generally of lightweight finned tube construction which have high bench efficiencies that do not reduce significantly at part load; the limit to their performance being the onset of condensation with its associated problems of corrosion and drainage.

From 1983 onwards purpose designed condensing boilers have been sold in Great Britain. These boilers have even higher bench efficiencies, good part load performance and also benefit from increased efficiency due to condensation as the return water temperature is reduced.

Traditional, high efficiency and condensing boilers are all currently on sale in Great Britain and frequently, combinations of the different types of boiler exist in the same boiler room.

CONDENSING BOILERS

Condensing boilers differ chiefly from traditional and high efficiency boilers in their ability to recover and use some of the latent heat produced when moisture within the flue products is condensed. The temperature at which moisture starts to condense is known as the dew point. The actual dew point for flue products within a boiler varies with combustion excess air levels and any air dilution of the flue products prior to the condensing heat exchanger. Although condensing boilers can benefit from recovering this latent heat, it does not follow that condensation will always occur within the boiler, because condensation can only take place if the flue products have been cooled below their dew point (about 55°C for natural gas boilers).

Although other fuels produce water vapour during combustion, natural gas has a particularly high proportion of moisture in its flue products. This fact, plus a low sulphur content which means less acidity in the condensate, makes natural gas the ideal choice of fuel for condensing boiler design. About 10% of the heat input to a boiler can be lost as latent heat in traditional and high efficiency boiler designs. It is partly the recovery of this heat and partly the extra sensible heat extracted which enables condensing boilers to be so efficient.

Whether surface temperatures in the boiler reach 55°C depends on the boiler design, the heating system installed and the controls used.

To produce condensate the boiler must have an efficient heat exchanger so that the flue gases are sufficiently cooled. An example is shown in figure 2. Once the return water to the boiler drops below the dew point condensation begins to occur. The extent depends on the quality of the boiler design and the actual return temperature. The theoretical maximum rate of condensate production is between 140-150 ml/h per kW input although typical boilers would produce about half of this value. Figure 3 shows typical curves for efficiency, condensate production and flue exit temperature all against return water temperature (1).

Since condensing boilers were first developed in Europe the number of manufacturers offering these boilers has steadily grown. At least 17 manufacturers are making condensing boilers for the domestic and small commercial market (2), while in Great Britain, 9 manufacturers or importing agents are offering condensing boilers for the commercial market. The range of boiler output available is from 20kW to 1283kW.

LABORATORY TESTS

Three distinctly different condensing boilers have been examined in the R&D laboratories at Watson House. In the tests the setting of the boiler flow temperature thermostat was successively lowered. A given proportion of the boiler heat output was dissipated via a heat exchanger on the roof of the laboratory. The boiler thermostat then matches boiler output to perceived load. Consequently the heating load on the boiler can be varied as well as the flow temperature.

So that the part load efficiency curves obtained could be compared against previous curves from traditional and high efficiency boilers, the flow temperature was held constant. A series of curves at various different flow temperatures is needed to fully test a condensing boiler because lowering the flow temperature raises the efficiency of the boiler.

Three boilers were tested. One was based on a cast iron sectional design with an additional condensing heat exchanger and an induced draught fan incorporated to overcome internal resistance within the boiler. Atmospheric burners were used. Figure 2 shows a schematic of this boiler and Figure 4 gives the part load efficiency curves.

The second boiler tested had a lightweight finned tubed heat exchanger and a burner that was fully premixed. Figure 5 shows its part load efficiency curves.

The third had a natural draught flue and modulating atmospheric burners. Figure 6 shows the part load efficiency curves for this boiler.

Tests have verified the capacity of commercial condensing boilers to achieve high gross efficiencies for space heating duties.

All of these condensing boilers are different and to some extent this must be reflected in the way they are installed and controlled if they are to perform properly. All the manufacturers and agents provide guidelines for their particular boilers and British Gas has produced a general guide. The guides aim to ensure safe and correct installation while pointing the way towards high performance. The next section evaluates some of the installation techniques that benefit condensing boilers.

SYSTEMS FOR CONDENSING BOILERS

The primary heat exchanger section of most condensing boilers must be protected against the formation of condensate because the material of construction and boiler design would not withstand the corrosive effect of condensate on the heat exchanger or burners. The majority of condensing boilers have limits on the return temperature that can be allowed to enter their primary heat exchanger. Only if the limit is set at a very low level by the manufacturer i.e. 25°C or less, can the condensing secondary heat exchanger and primary heat exchanger be connected in series. Such a boiler can be placed in a simple heating circuit (Figure 7) and controlled directly on the boiler by a weather compensating control. Figure 8 shows how this arrangement interacts with the external compensator control and water temperature and actually gives higher performance at part loads.

Where protection of the primary heat exchanger is required, a three port valve is used to maintain temperatures above the design low limit (Figure 9). In such a circuit return water at reduced temperatures will pass through the condensing heat exchanger when the three port valve is controlled by a weather compensator.

In either the simple circuit (Figure 7) or the three port valve circuit (Figure 9) the effect of reduced water temperatures passing through the condensing heat exchanger is to raise boiler efficiency. Nearly all commercial condensing boilers can be installed in one of these two ways.

Certain types of high temperature heating circuits are unsuitable for condensing boilers, such as circuits with fan convector emitters or where a high head of water pressure has enabled flow temperatures of above 100°C to be used.

Conversely, low temperature circuits will be beneficial (although not necessarily cost effective). Such circuits might include underfloor heating or where the radiators are oversized - possibly due to extensive insulation after the original design and installation (3).

These simple heating circuits are frequently modified to enhance the performance of the condensing boilers. Air heating coils may be added into the circuit or a particularly low temperature zone designed into the building. If service hot water can be included in the space heating circuit, separate summer and winter circuitry sometimes becomes necessary to prevent the condensing heat exchanger suffering damage when the heating circuit is isolated during the summer.

MONITORING

To understand what effect these designs have on the boilers' performance, a series of monitoring studies has been carried out. Two levels of monitoring package have been used to study installed condensing boilers. Detailed monitoring, using a data logger has been used on sites of particular interest. Times of operation of the boiler(s) and pumps were recorded along with gas consumption, flow and return water temperatures, outside air and room/zone temperatures, water flow rate(s) and condensate volume.

The collected data were processed to give both graphic temperature/operational data (Figure 10) and analysed results of daily efficiencies, maximum and minimum temperatures, degree days, heat input and heat output and flow rates.

The analysed data were used to review the boiler operation and determine whether the site was functioning as expected. Accumulated results are used to produce seasonal system/boiler(s) efficiencies.

In contrast to the detailed monitoring described above, a large number of sites have been studied, with limited monitoring only. Boiler running time, time clock 'on' time, gas consumption and condensate production were measured. In some locations heat meters were also installed.

FIELD TRIAL RESULTS

The field trial sites have been carefully chosen to reflect the range of condensing boilers and air heaters available in Great Britain as well as the types of commercial premises. All the trials have been aimed at the commercial market but boiler capacity from 45kW up to 469kW has been chosen. As wide a variety of building function, age and method of construction as possible has been covered by the trials. The early sites monitored were mainly based on simple heating circuits, but later, mixed condensing and non-condensing boiler circuits and circuits including service hot water have been examined.

Table 1 summarises the results from the field trial sites monitored to date. Figure 11 shows some of the corresponding circuit diagrams.

The results are given as seasonal efficiencies (i.e. the total efficiency at the end of the heating season based on distributed heat and total gas consumed).

The early sites monitored were all simple heating circuits and the boilers could all be controlled directly by weather compensating controls. Service hot water was provided separately. These sites, the London primary school, the Bracknell restaurant and the Liverpool old peoples home were single boiler replacement installations. The boiler room pipework was left largely unaltered to help keep installation costs low. The lack of boiler back up facilities at these sites meant boiler reliability was as important as efficiency when the boilers were selected. The customers have all been pleased with these installations and similar replacement installations have been dealt with in the same way.

Larger replacement installations were at sites with two or more boilers. Again, the service hot water was separated from the heating boilers. The main reason for interest in these sites - the Blackpool secondary school and the Buckinghamshire educational establishment was that they had both condensing and non-condensing boilers connected to the heating circuit. The boilers' individual performance was averaged during the heating season under this arrangement. This led to higher efficiencies than found in most non-condensing boiler only sites, but less than could be achieved if condensing boilers alone were used. The obvious advantage of reduced installation costs and consequently short payback periods compensated for the lower efficiencies (compared to condensing boilers alone situations). There were some disadvantages - all associated with commissioning - such as the need to balance the circuits carefully between unlike boilers and the problems of setting up compensator curves and sequence control settings. This attention to detail can significantly affect the overall sites performance and is the most significant lesson learnt with mixed installations.

The last type of site studied could be called innovative. These sites included those with novel heat emitters, such as found at the Hampshire museum (underfloor heating) and the Manchester Office (high output radiators and air handling coils). These sites were sized for reduced return water temperatures. Both these installations were in new buildings and full advantage had been taken of high insulation to enable these return water temperature reductions. As expected very high efficiencies have been obtained. These sites have satisfied both the designer and customer although installation costs tend to be carried by the overall site construction costs.

A further two sites in this category - the London office block and the London old peoples home have used mixed condensing and non-condensing boilers but with the addition of an extra condensing heat exchanger preheating the service hot water. A necessary buffer store accommodates any differences in hot water and heating demands. These sites already had service hot water circuits linked to the heating boilers prior to the boilers replacement. Although requiring care in design and installation, the sites have worked well and excellent efficiencies are being obtained. The service hot water demand also extends the boiler running time and thus reduces payback periods. No significant problems have occurred at this type of installation and the customers in question have considered other sites for the same treatment.

Except for the service hot water sites and the underfloor heating site, where extended periods of condensing operation occurred, the usual condition was for condensing operation to occur for 75% of the time and 50% of the gas load (with the condensing boiler always the lead boiler).

PAYBACK ANALYSIS

Table 1 includes the marginal additional costs per kW output for most of the sites monitored. The costs are the extra costs incurred during installation and the additional boiler price. Therefore, the figures include any marginal flueing cost, the condensate drain cost and any essential additional controls. The extra boiler cost is compared with alternative high efficiency boilers (but non-condensing). These figures are based on 1986 prices.

The costs quoted cover a wide range of boiler manufacturers and boiler models. The smaller boilers from each manufacturer are more expensive to install reflecting the absence of high efficiency boilers for certain heat outputs and also the effect of increasing significance for the drain and flue costs on a per kW output basis.

Where detailed analysis is available, payback periods have been calculated. These fall within the 2-5 year range. Figure 12 relates relative cost per kW output and payback for various levels of annual boiler running hours.

In order to achieve short paybacks, the condensing boilers have to be installed and running properly (i.e. seasonal efficiencies of 88%). Under these circumstances the marginal additional boiler costs/kW output are less significant than total annual boiler running hours.

Oversizing either the boiler plant or the heating emitters is unlikely to significantly improve the performance of the system and will inevitably lead to worse payback times.

FUTURE DEVELOPMENTS

Existing systems and boilers have been shown to be cost effective in both retrofit conventional installations and in certain purpose designed low temperature circuits. For most applications and condensing boiler designs, service hot water is best separated from the space heating boilers. Where service hot water demand is high, the specialised system installed at the London Office block is worth considering. Another alternative would be the installation of the condensing water heaters becoming available in Europe and Great Britain and the direct contact water heaters (wet condensing boilers (2)) that have just been developed by British Gas for the industrial and large commercial market.

Further into the future, technology exists which can raise the dew point within a condensing boiler to above 70°C. One way of doing this is to raise the humidity in the boiler. Such a boiler exists in France (4,2) but is prohibitively expensive for all but specialised installations.

Another possibility is to pressurise the combustion chamber of a boiler by 1 Bar or more. This has been done experimentally for oil firing using truck turbo chargers (5) in Sweden. With dew points of over 70°C, conventional heating design would allow condensing boilers to condense throughout the season and service hot water circuits would become easier to design. Such systems could have gross seasonal boiler efficiencies of 95% or above.

CONCLUSIONS

Laboratory tests by British Gas on commercial condensing boilers have shown part load efficiencies significantly higher than traditional or high efficiency boilers.

The marginal additional installation costs per kW output quoted in Table 1 show a spread of from £6.0/kW to £12.0/kW. The highest figures tended to come from totally condensing boiler installations and the smaller boiler sizes.

The field trial results obtained showed that very high efficiencies (seasonal efficiencies 75% to 90%) can be attained. Together with the marginal additional costs simple payback periods of 2-5 years relative to high efficiency boilers have been calculated for some of the sites. Boiler running times greatly affect these payback periods.

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TABLE 1: COMMERCIAL CONDENSING BOILER FIELD TRIAL RESULTS OBTAINED BY WATSON HOUSE

SITE	INPUT kW	BOILERS	HEATING SYSTEM	CONTROLS	TOTAL BOILER RUNNING TIME (HRS)	HEATING SEASON	TOTAL CONDENSATE (LITRES)	GROSS EFFIC (%)	EXTRA COSTS PER kW OUTPUT * (SEE BELOW)
PRIMARY SCHOOL, LONDON	330	1 CONDENSING	HEATING ONLY, RADIATORS & CONVECTORS	COMPENSATOR ON BOILER	1430	84/85	2700	88.1	£7.6
MUSEUM, HAMPSHIRE	80	3 CONDENSING	HEATING ONLY, UNDERFLOOR & RADIATORS	COMPENSATOR ON BOILER(S)	11,000	84/86	12,000	89.9	£7.5
SECONDARY SCH, BLACKPOOL	469+ 397	1 CONDENSING 1 CONVENTIONAL	HEATING ONLY, RADIATORS	COMPENSATOR ON BOILER(S)	2288	85/86	7643	82.9	£9.0
EDUCATIONAL ESTABLISHMENT, BUCKINGHAMSHIRE	157 + 145	1 CONDENSING 1 CONVENTIONAL	HEATING ONLY, CONVECTOR RADIATORS: PIPEWORK CHANGES 1986 (SEE TEXT)	SEQUENCE CONTROLS	3236	85/86 86/87 TO DATE	0 620	73.2 75.1 TO DATE	£6.0
OFFICE BLOCK, MANCHESTER	332	2 CONDENSING	HEATING ONLY, CONVECTOR RADIATORS	ENERGY MANAG-EMENT SYSTEM	-	86/87 TO DATE	3300	83.5 TO DATE	£11.1
OFFICE BLOCK, LONDON	261+ 232	1 CONDENSING 1 CONVENTIONAL	HEATING AND SERVICE HOT WATER	COMPENSATION ON 3 PORT VALVE	-	86/87 TO DATE	3540	83.8 TO DATE	NOT KNOWN
OLD PEOPLE'S HOME, LONDON	130+ 232	1 CONDENSING 2 CONVENTIONAL	HEATING AND SERVICE HOT WATER	COMPENSATION ON 3 PORT VALVE	-	TO BE MONIT-ORED 87/88	-	-	BEING INSTALLED
OLD PEOPLE'S HOME, LIVERPOOL	45	1 CONDENSING	HEATING ONLY, RADIATORS	LOW COST BEM CONTROL	-	86/87 TO DATE	-	87 ESTIMATED	£11.0
RESTAURANT, BRACKNELL	58	1 CONDENSING	HEATING ONLY, RADIATORS	LOW COST BEM CONTROL	-	86/87 TO DATE	-	87 ESTIMATED	£12.0
SECONDARY SCH, SURREY	360	6 HIGH-EFFICIE-NCY MODULES (FOR COMPARISON ONLY)	HEATING ONLY, ZONED RADIATORS	ENERGY MANAGE-MENT SYSTEM	-	85/86	NON CONDENSING	81	-
WAREHOUSE, LUTON	468	4 CONDENSING AIR HEATERS (FOR COMPARISON ONLY)	AIR	ROOM THERMOSTATS	2300	85/86	-	93.6	£3.7

*MARGINAL ADDITIONAL COSTS PER kW OUTPUT AT 1986 PRICES

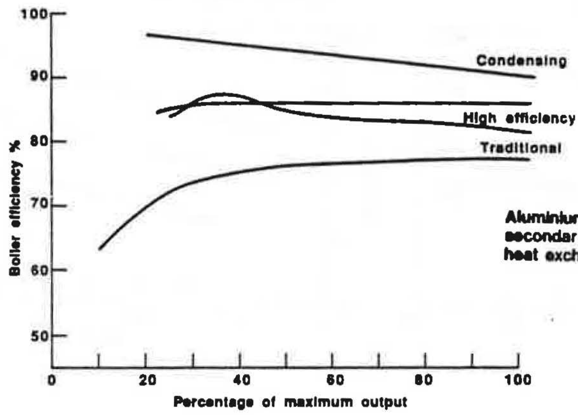


Figure 1 Commercial boiler efficiency curves

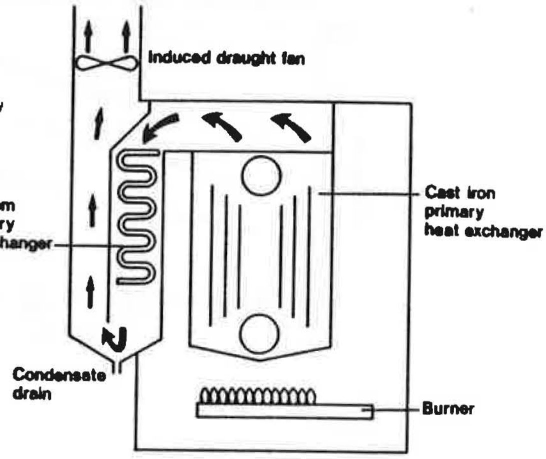


Figure 2 Schematic diagram of a heavyweight condensing boiler

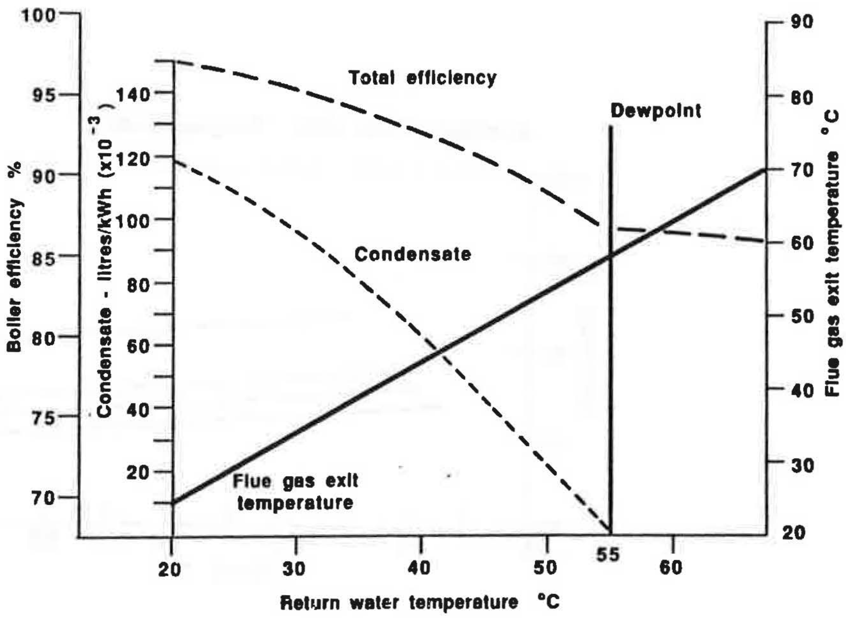


Figure 3 Typical performance curves for a heavyweight condensing boiler

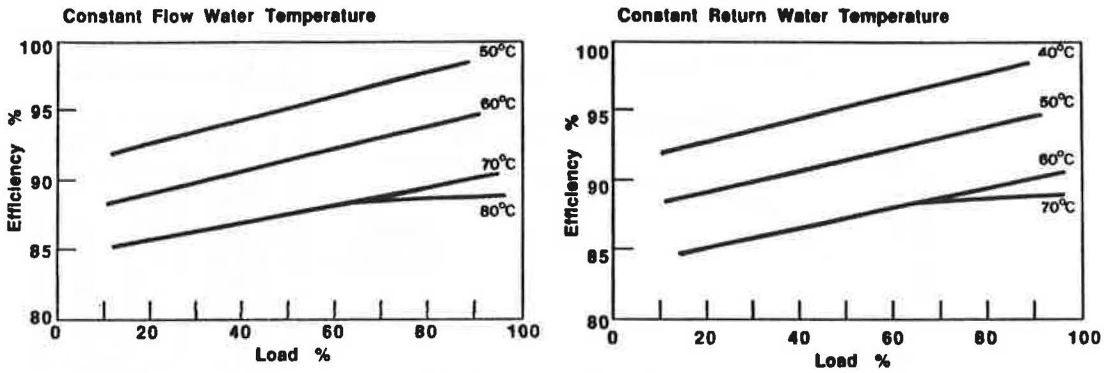


Figure 4 Part load efficiency curves for a heavyweight condensing boiler

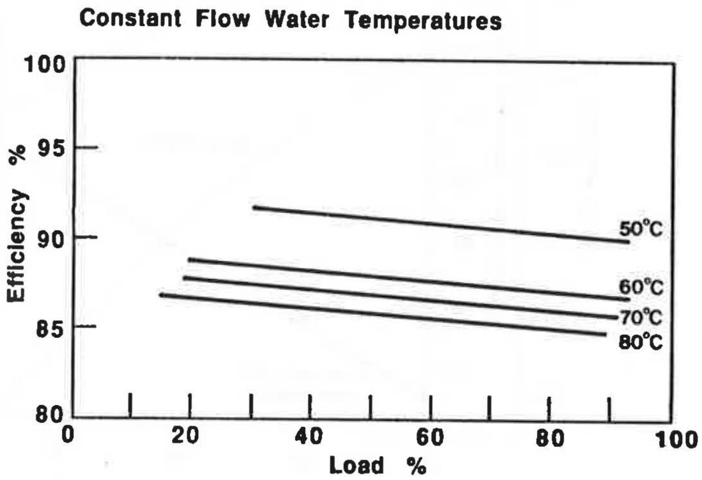


Figure 5 Part load efficiency curves for a lightweight condensing boiler

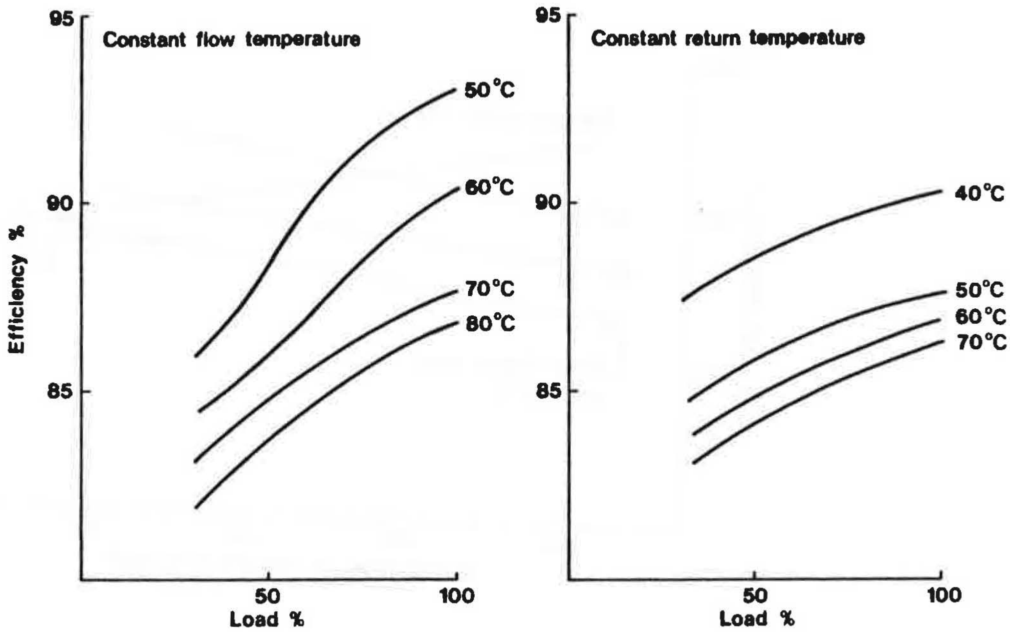


Figure 6 Part load efficiency curves for a fully modulating lightweight condensing boiler

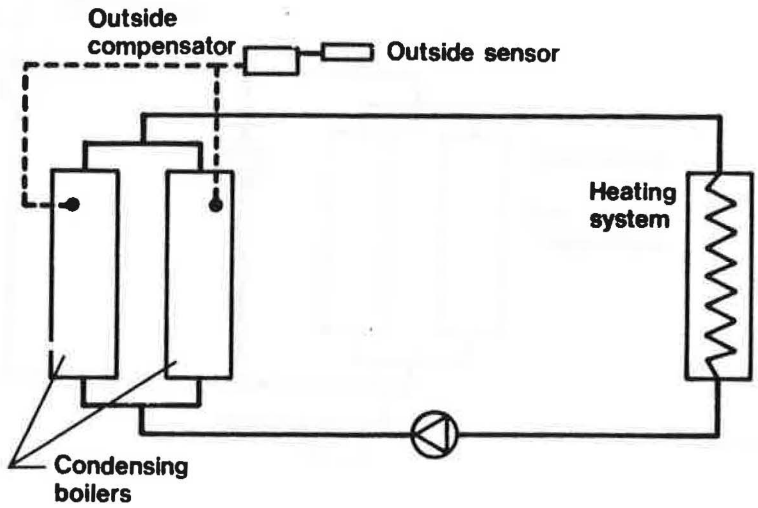


Figure 7 Simple compensated heating circuit

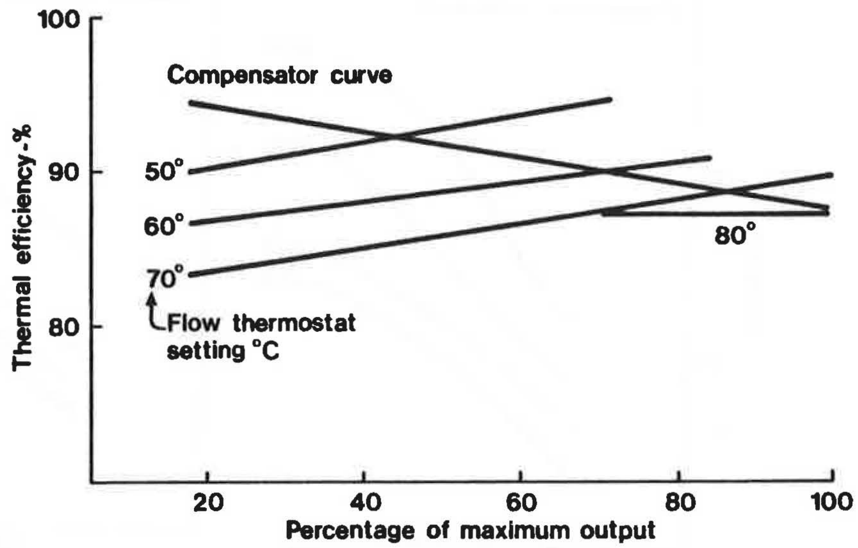


Figure 8 Operating curve for a condensing boiler under direct compensator control

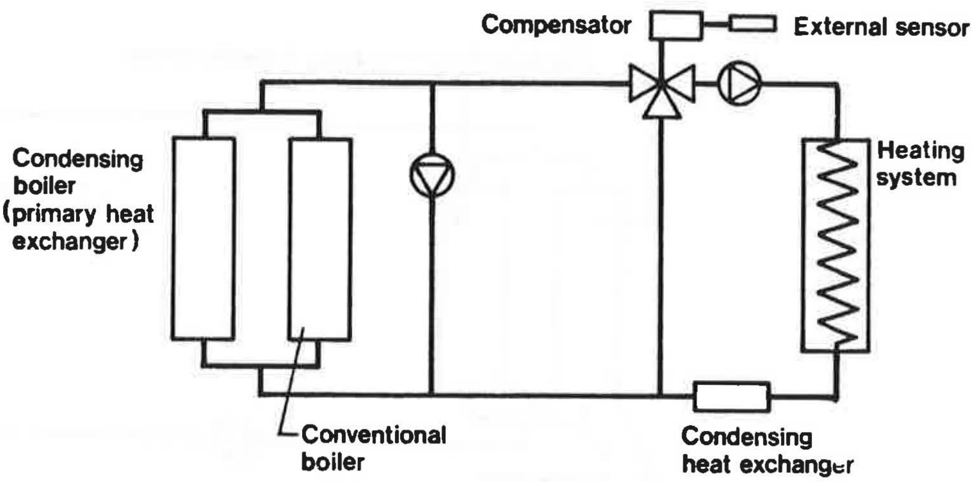
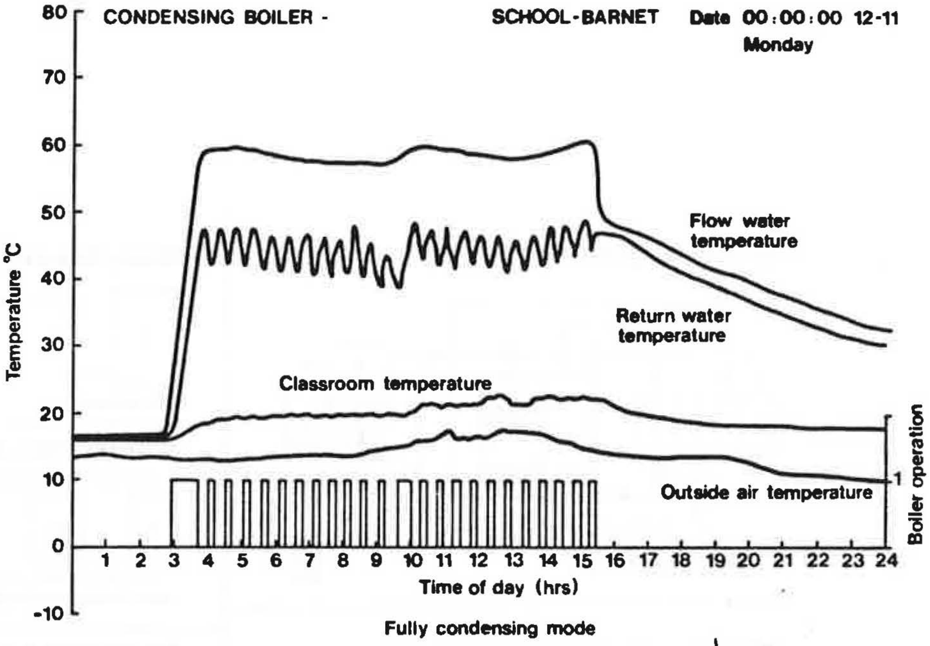


Figure 9 Condensing boiler in a three port valve system



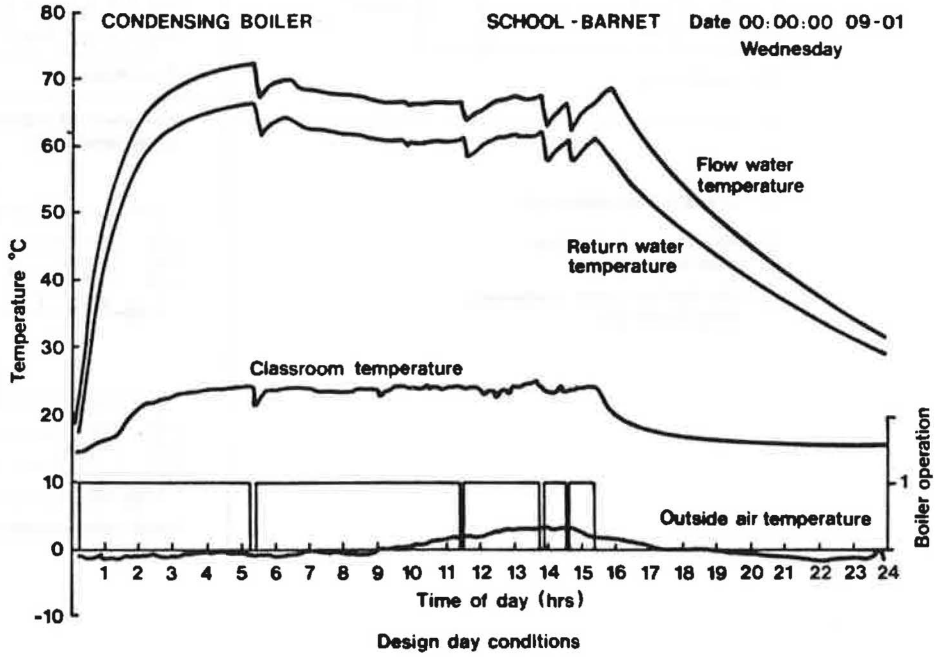


Figure 10 Typical results from a field trial site

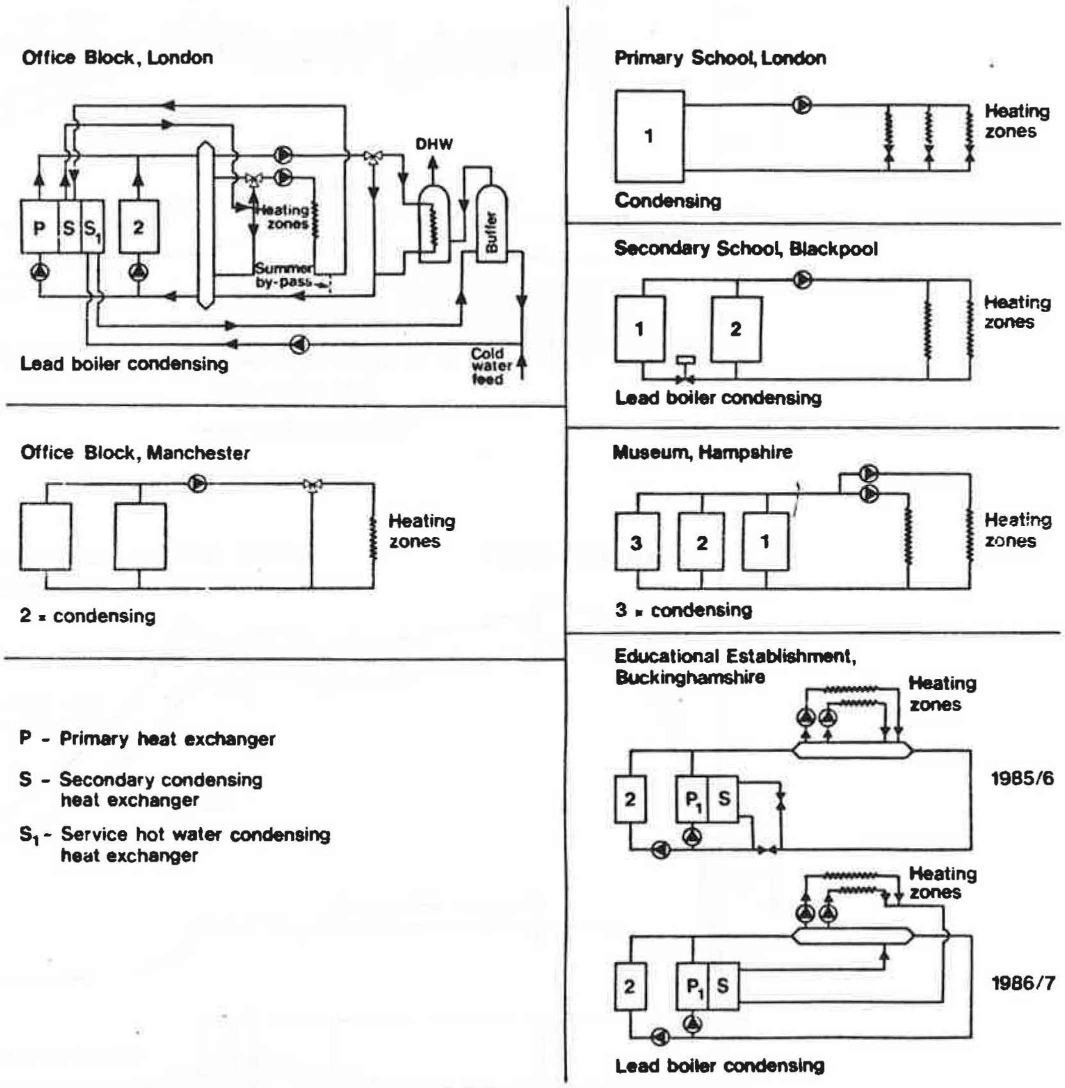


Figure 11 Boiler circuit diagrams for the field trial sites

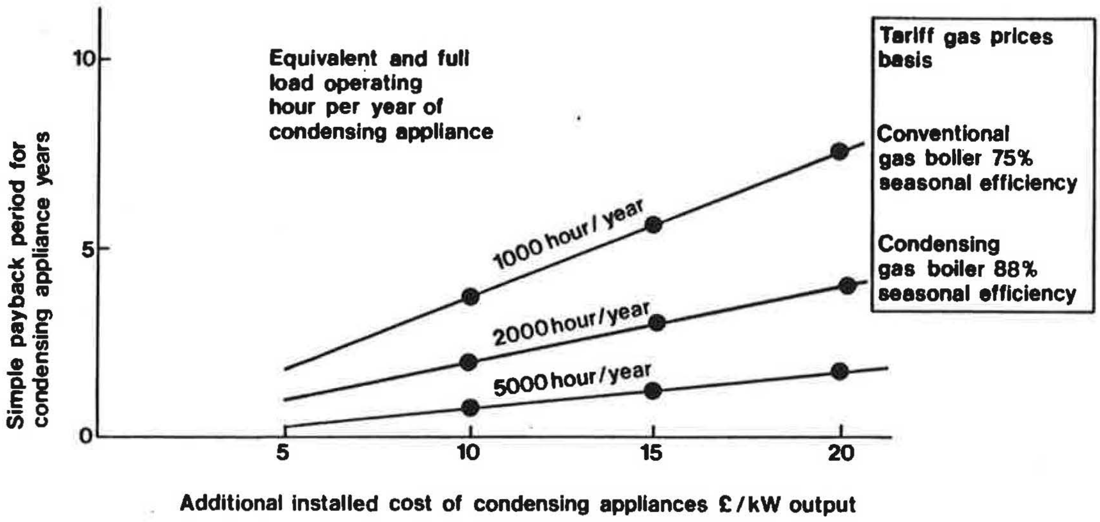


Figure 12 Variation of simple payback with operating hours and installed cost of condensing boiler

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TECHNICAL MEMORANDUM NO.4

"CIBSE Design Notes for the Middle East"

D W Wood - (Diagrams)

TABLE 1

SUMMARY OF DESIGN CONDITIONS

LOCATION				DESIGN DATA				
				SUMMER				WINTER
Station	Lat.	Long.	Alt. M	Month	Dry Bulb °C	Average Diurnal Range °C	Wet Bulb °C	Dry Bulb
AFGHANISTAN								
Kabul	34°30'N	69°13'E	1815	August	37	15	20	-8
BAHRAIN	26°12'N	50°30'E	5	July	39	6	28	15
ETHIOPIA								
Addis Ababa	9°20'N	38°45'E	2445	May	27	14	17	5
Asmara	15°17'N	38°55'E	2292	April	28	14	16	6
Djibouti	11°36'N	43°09'E	7	July	45	8	28	22
IRAN								
Tehran	35°41'N	51°25'E	1220	July	40	12	27	-3
Abadan	30°21'N	48°16'E	3	August	48	14	31	8
Bandar Abbas	27°11'N	56°17'E	9	July	43	9	32	13
Esfahan	32°34'N	51°44'E	1771	July	39	15	20	-4
Kermanshah	34°21'N	47°06'E	1306	July	40	19	25	-5
Mashad	36°17'N	59°36'E	946	June	37	13	22	-6
IRAQ								
Baghdad	33°20'N	44°24'E	34	August	47	15	24	4
Basra	30°34'N	47°47'E	2	July	46	13	29	7
Mosul	36°19'N	43°09'E	223	July	47	17	25	2
ISRAEL								
Eliat	29°33'N	34°57'E	2	August	44	13	26	10
Jerusalem	31°47'N	35°13°E	757	June	36	11	21	5
Haifa	32°48'N	34°59'E	10	May	38	9	25	9
JORDAN								
Amman	31°57'N	35°57'E	777	August	38	12	22	4
KUWAIT								
Kuwait Airport	29°13'N	47°59'E	55	August	48	14	23	8
Kuwait City	29°21'N	48°00'E	5	August	45	8	31	9
LEBANON								
Beirut	33°54'N	35°28'E	34	August	33	7	26	7
LIBYA								
Benghazi	32°06'N	20°04'E	25	June	38	8	24	10
El Adem	31°51'N	23°55'E	160	June	40	11	23	6
Idris	32°41'N	13°10'E	80	July	45	13	26	7
Jaghbub	29°45'N	24°31'E	15	June	45	15	25	7
Tripoli	32°54'N	13°11'E	22	July	41	11	29	9
OMAN								
Masira Island	20°41'N	58°54'E	16	May	35	No Daily	Averages	
Muscat	23°37'N	58°35'E	5	June	43	6	34	19
Salalah	17°03'N	54°06'E	17	June	33	No Daily	Averages	
Seeb Airport	23°37'N	58°35'E	5	June	46	10	*	14
PAKISTAN								
Karachi	24°48'N	66°59'E	4	May	39	9	30	13
Lahore	31°35'N	74°20'E	214	June	46	15	26	4
Peshnar	34°01'N	71°34'E	354	July	46	14	29	4

* insufficient data available

TABLE 1 - continued

LOCATION				DESIGN DATA				
				SUMMER				WINTER
Station	Lat.	Long.	Alt. M	Month	Dry Bulb °C	Average Diurnal Range °C	Wet Bulb °C	Dry Bulb
QATAR								
Doha	25°16'N	51°33'E	8	August	41	No Daily Averages		
SAUDI ARABIA								
Dhahran	26°16'N	50°10'E	23	July	46	No Daily Averages		
Jeddah	21°28'N	39°10'E	6	July	41	No Daily Averages		
Medina	24°33'N	39°43'E	646	July	46	15	*	7
Tabouk	28°22'N	36°35'E	773	July	42	15	*	-2
Taif	21°29'N	40°32'E	1471	July	37	10	*	3
Yanbu	24° 7'N	38° 3'E	6	June	43	14	*	9
Kamis-Mushait	18°18'N	42°48'E	2066	July	32	13	*	3
Riyadh	24°39'N	46°42'E	590	July	45	No Daily Averages		
SOMALIA								
Bosaso	11°17'N	49°10'E	7	September	42	9	33	20
Berbera	10°26'N	45°02'E	14	June	44	9	32	20
Hargeisa	09°29'N	44°05'E	1332	July	33	13	21	11
Mogadishu	02°02'N	45°21'E	12	April	34	6	29	23
SUDAN								
Khartoum	15°37'N	32°33'E	390	June	45	15	25	16
Obeid	13°11'N	30°14'E	574	May	42	15	23	13
SYRIA								
Damascus	33°30'N	36°20'E	720	August	41	14	22	2
Aleppo	36°14'N	37°08'E	390	August	42	No R.H. Figures		
TURKEY								
Adana	36°59'N	35°18'E	25	June	38	12	25	4
Ankara	39°57'N	32°53'E	861	July	36	12	21	-4
Istanbul	41°06'N	29°03'E	114	July	34	8	24	2
Izmir	38°27'N	27°15'E	28	August	38	11	24	4
UAE								
Abu Dhabi	24°29'N	54°21'E	6	July	46	10	33	14
Dubai	25°15'N	55°20'E	8	July	46	12	29	14
Sharjah	25°20'N	55°24'E	5	August	44	12	33	13
UAR								
Alexandria	31°12'N	29°53'E	32	June	37	9	26	10
Aswan	23°58'N	32°47'E	193	August	45	16	24	9
Cairo	29°52'N	31°20'E	116	June	42	13	24	9

TABLE 2

TYPICAL LOCATION DATA SHEET

ETHIOPIA

PLACE : Addis Ababa

Latitude 9^o 02' N.
Longitude 34^o 45' E.
Altitude 2408 m.

Period : 1941-1970

DATA	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Temperature °C												
Average daily maximum	23	24	25	24	25	23	20	20	21	22	23	22
Average daily minimum	6	7	9	10	9	10	11	11	10	7	5	5
Average monthly maximum	26	26	27	27	27	27	25	24	24	25	24	24
Average monthly minimum	1	4	4	7	7	7	8	8	6	3	1	-1
Absolute maximum	27	28	29	30	30	29	27	25	25	25	26	25
Absolute minimum	-2	0	-4	4	2	4	7	7	4	2	0	-2
Relative Humidity %												
Average at 0530	80	82	81	86	76	87	91	92	90	81	82	81
Average at 1130	38	47	45	47	39	52	65	67	58	40	40	33
Average daily maximum												
Average daily minimum												
Rainfall mm												
Monthly average	13	35	67	91	81	117	247	255	167	29	8	5
Maximum in 24 hours	36	38	79	65	43	49	67	57	43	48	34	44
Sunshine												
Average daily	-	-	-	-	-	-	-	-	-	-	-	-
Evaporation (Class A pan) mm												
Average daily	-	-	-	-	-	-	-	-	-	-	-	-

Source: MET.O.856d, Part 4

TABLE 3

Comparison of Design Conditions

AREA	REVISED TM 4		CIBSE GUIDE TABLE A2.22		ASHRAE 1% DESIGN	
	DB	WB	DB	WB	DB	WB
Addis Ababa	27	17	28	19	29	19
Asmara	28	16	28	19	28	18
Bahrain	39	28	42	33	-	-
Cairo	42	24	41	22	39	24
Khartoum	45	25	45	23	43	25
Mogadishu	34	29	33	29	33	28
Tripoli	41	29	39	27	-	-

TABLE 4 - SAND AND DUST CONCENTRATIONS AT DHAHRAN, SAUDI ARABIA

CALCULATION OF MEAN ANNUAL PARTICULATE CONCENTRATION (MAPC)			
Condition	Hours of Occurrence ×	Condition Concentration mg/m^3 =	Annual Particulate Load Grains Per: mg/m^3
Sandstorm	36	69	2,484
Duststorm	400	34	13,600
Settling	470	5. 3	2,491
Clear	7,854	0.21	1,649
	8,760		20,224

$$MAPC = \frac{20,224}{8,760} = 2.31\ mg/m^3$$

TABLE V - MEAN ANNUAL PARTICULATE CONCENTRATIONS (MAPC)

Approximate Mean Annual Particulate Concentrations in Selected Cities in Saudi Arabia	
LOCATION	MAPC mg/m^3
Dhahran	2.31
Jeddah	3.19
Riyadh	4.83

FIGURE I

PSYCHROMETRIC CHART

Design conditions for Cairo

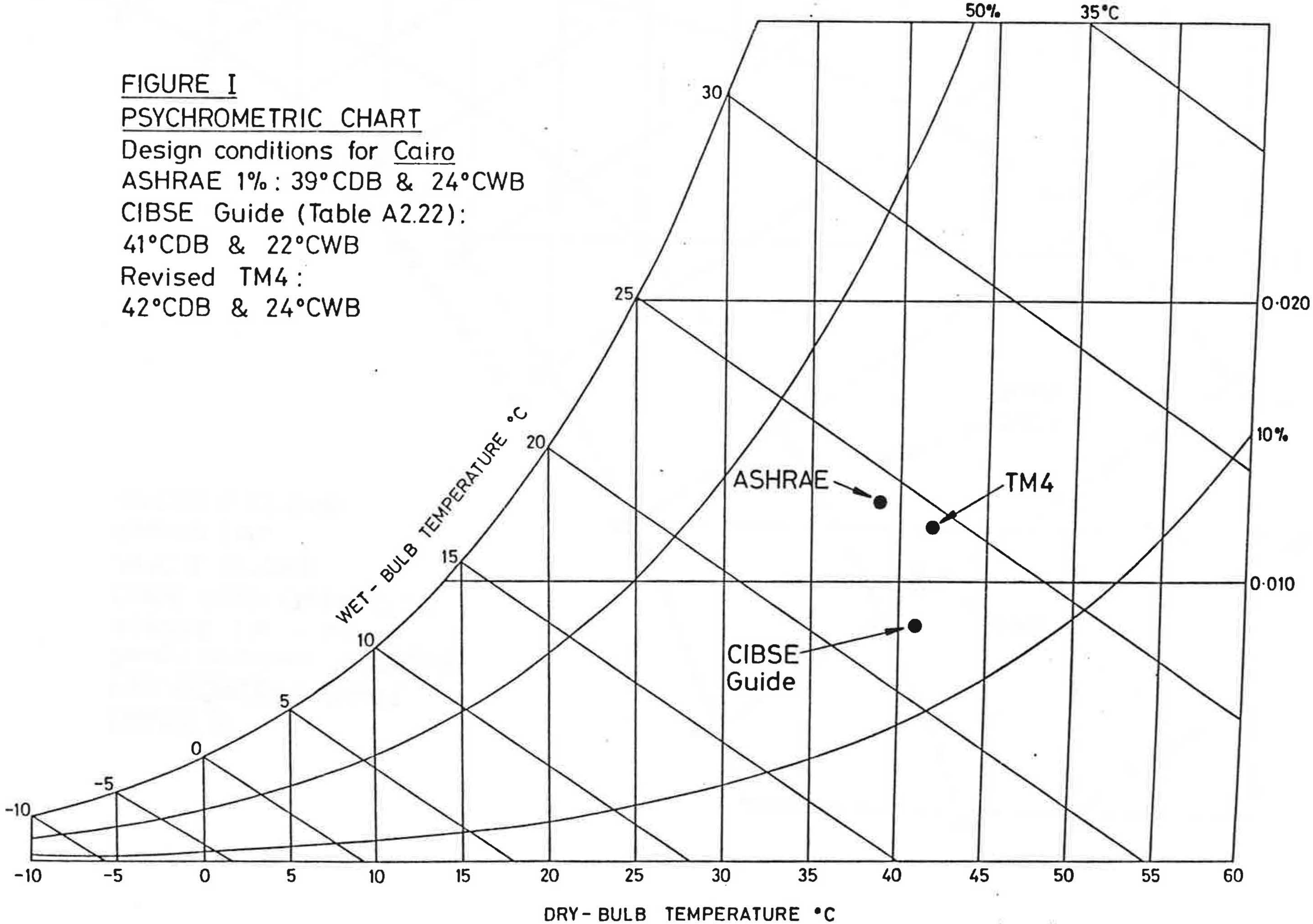
ASHRAE 1% : 39°CDB & 24°CWB

CIBSE Guide (Table A2.22):

41°CDB & 22°CWB

Revised TM4 :

42°CDB & 24°CWB



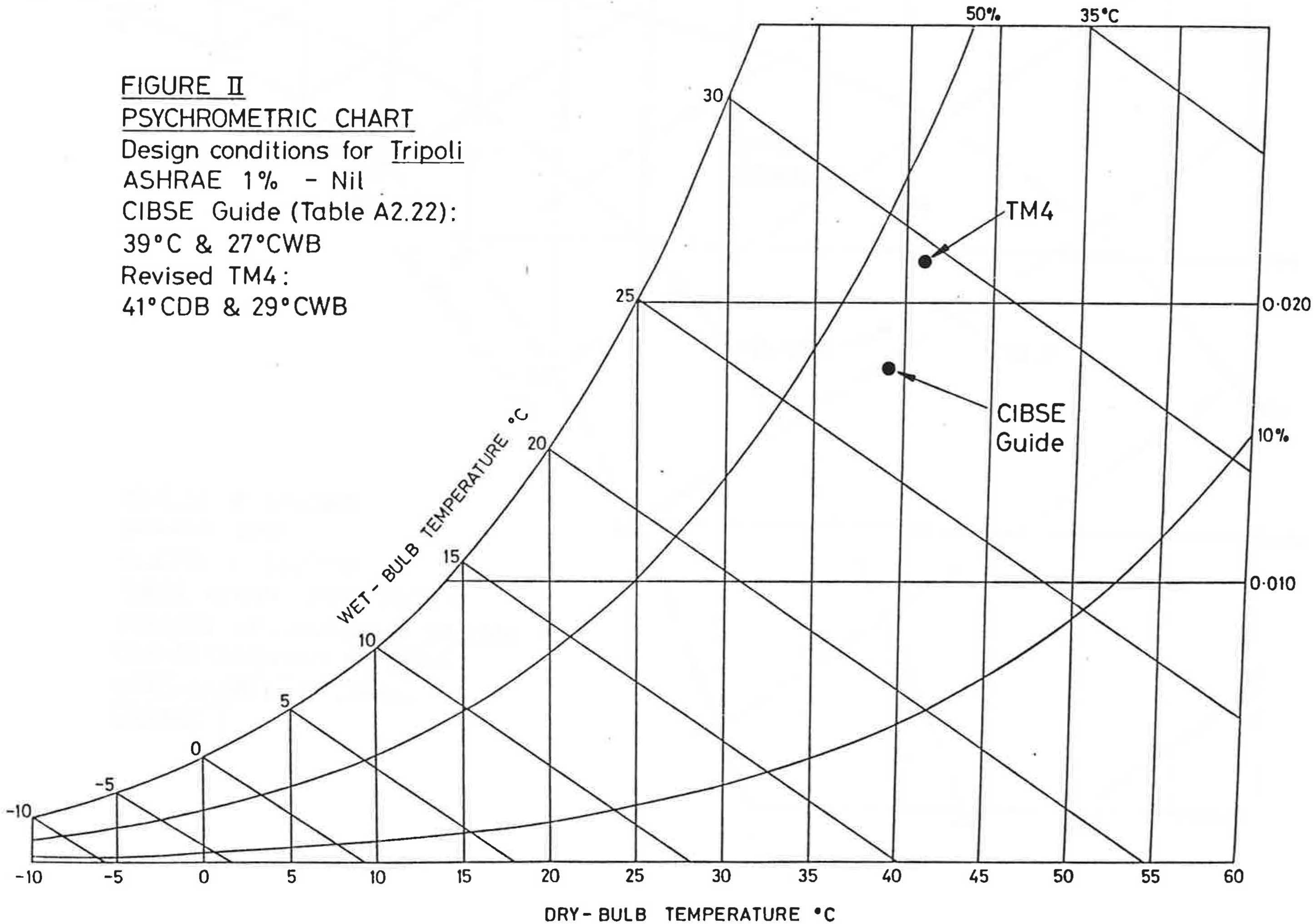
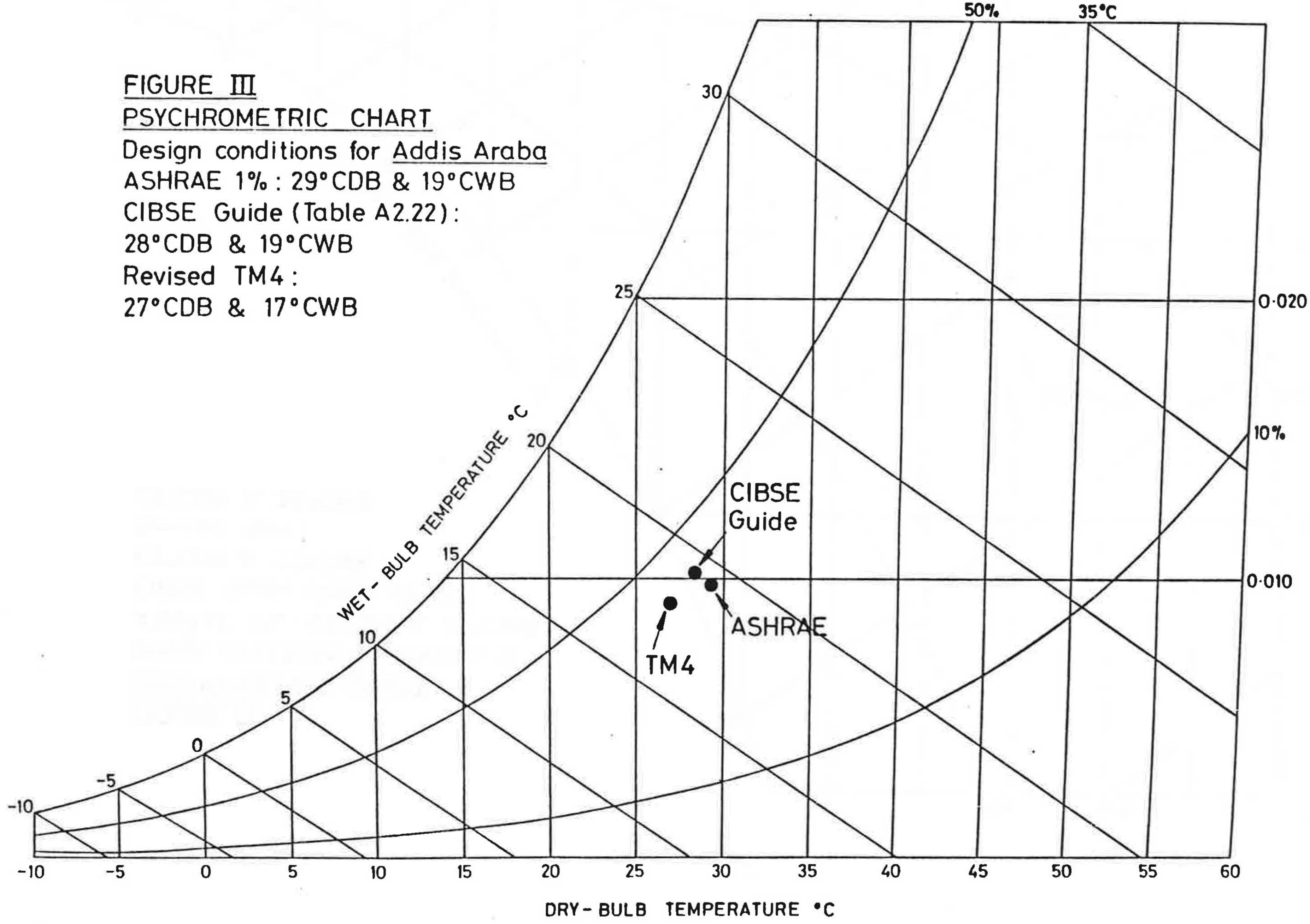


FIGURE II
PSYCHROMETRIC CHART
Design conditions for Tripoli
ASHRAE 1% - Nil
CIBSE Guide (Table A2.22):
39°C & 27°CWB
Revised TM4:
41°CDB & 29°CWB

FIGURE III
PSYCHROMETRIC CHART
Design conditions for Addis Araba
ASHRAE 1% : 29°CDB & 19°CWB
CIBSE Guide (Table A2.22):
28°CDB & 19°CWB
Revised TM4:
27°CDB & 17°CWB



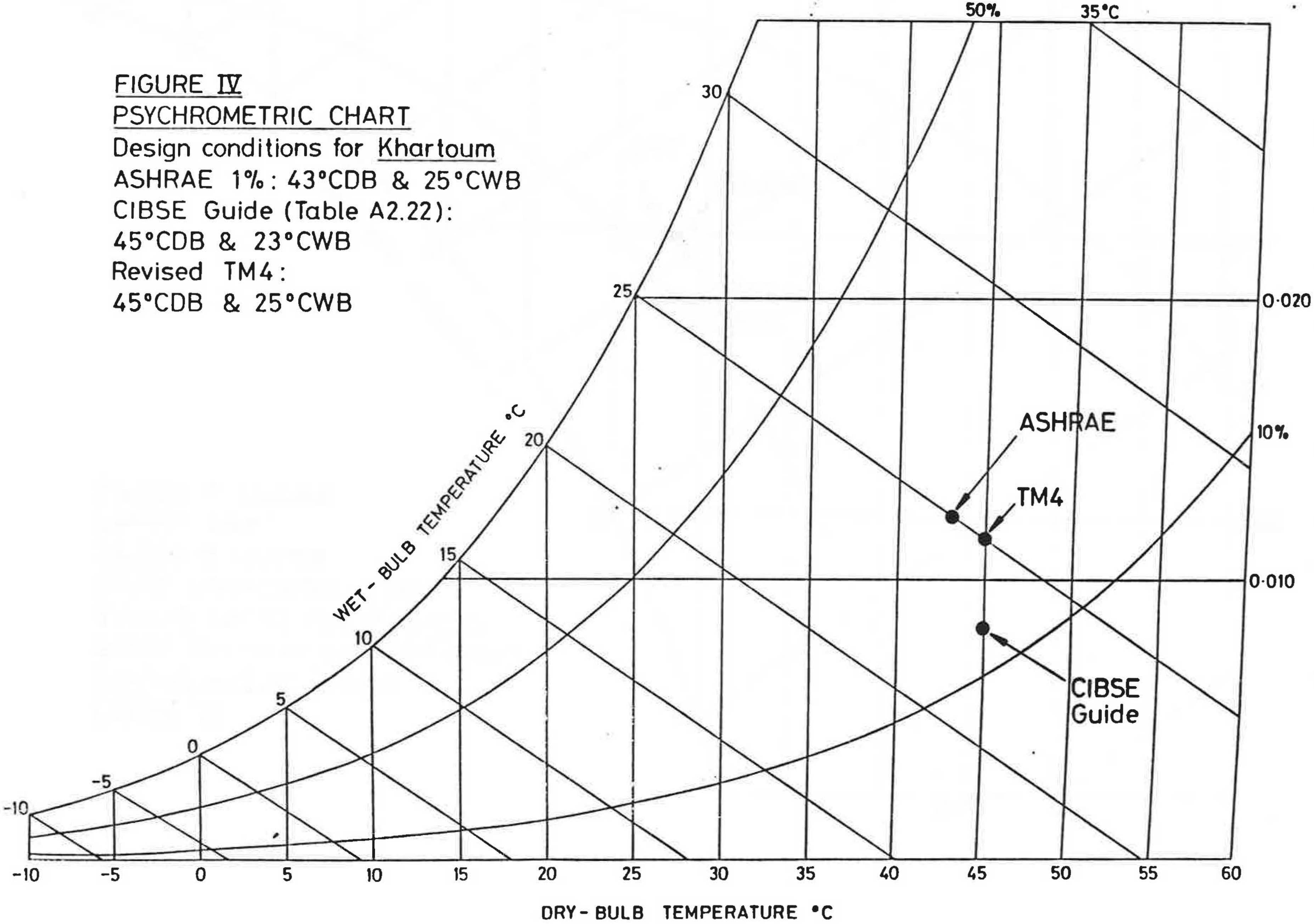


FIGURE IV
PSYCHROMETRIC CHART
Design conditions for Khartoum
ASHRAE 1%: 43°CDB & 25°CWB
CIBSE Guide (Table A2.22):
45°CDB & 23°CWB
Revised TM4:
45°CDB & 25°CWB

FIGURE V

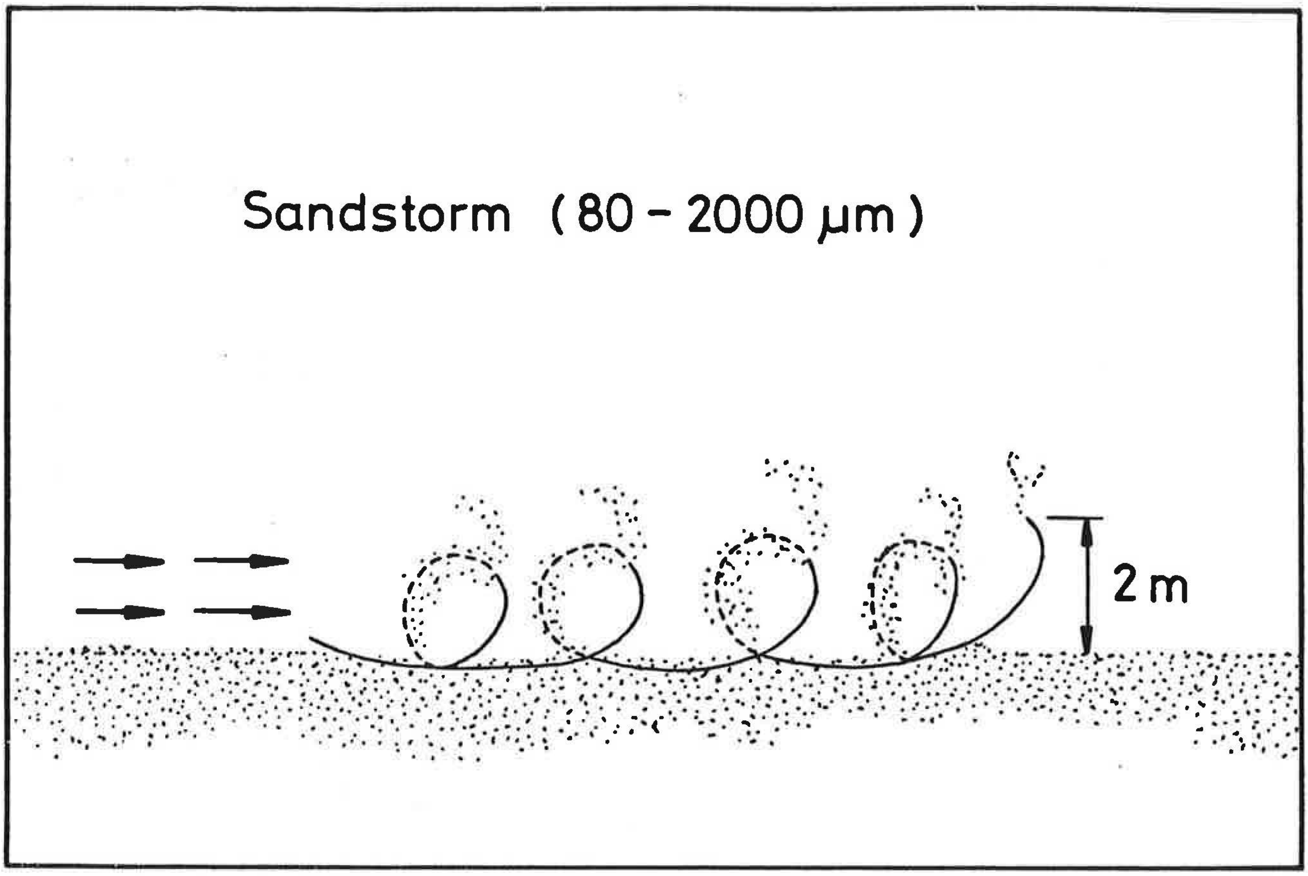
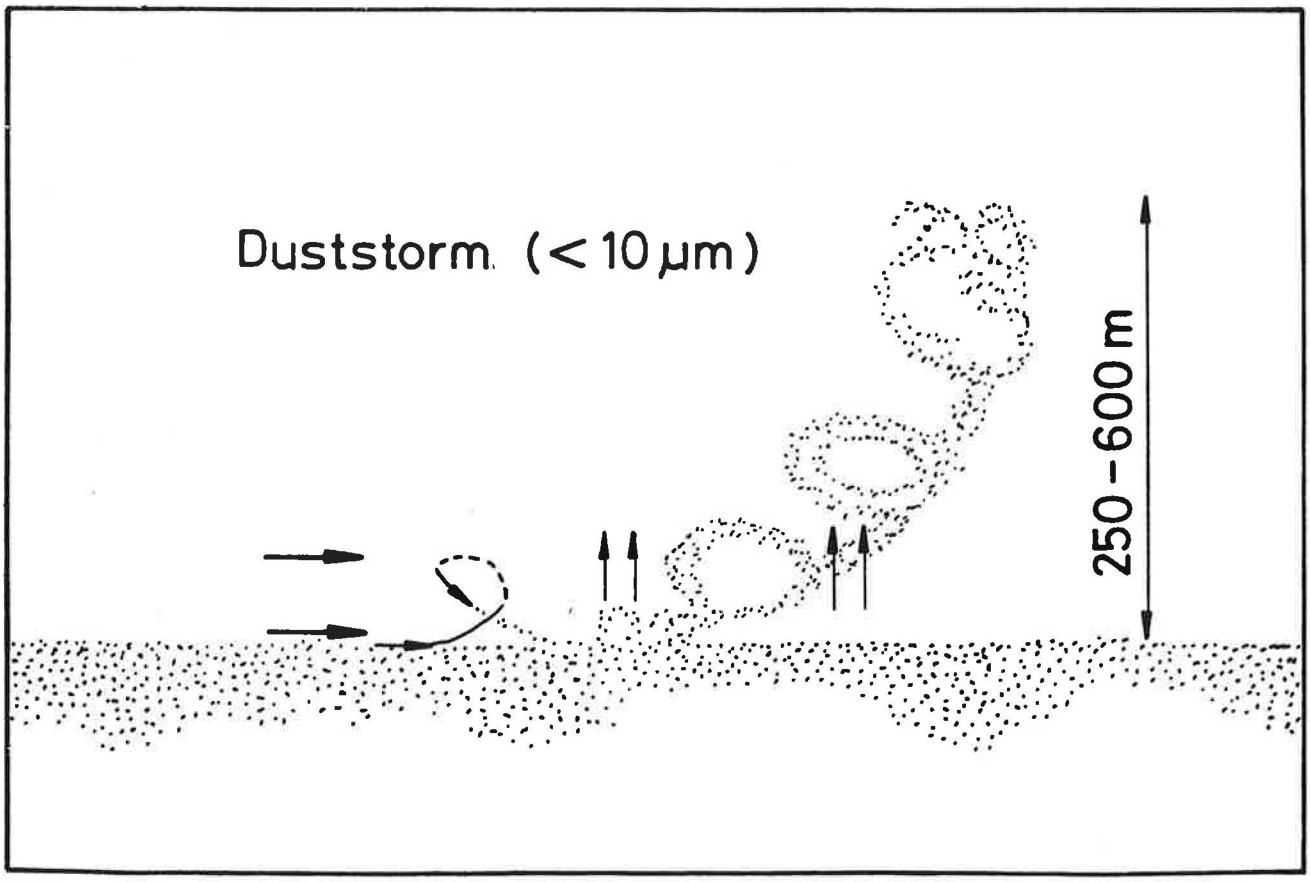


FIGURE VI



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Sketch No.

Date.

3862/81

THE SPA SCHOOL, HEAT-STORAGE FIELD TRIAL
- A NEW TECHNOLOGY FOR IMPROVING COMMERCIAL CENTRAL-HEATING SYSTEMS

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Cranfield Institute of Technology and British Gas plc have undertaken a collaborative programme of tests of a system which interposes a heat store between a boiler and a distributive central-heating network. In the commercial and institutional sector, this has culminated in a field trial of such a system at Spa School in London. It was predicted to lead to significant energy savings, to require a lower installed boiler capacity, and to reductions in installation costs for new and for some retro-fitted systems.
*
Specifically, a thermally-insulated 3235-litre hot-water store was installed in the circuit between the existing modular boiler set and the hydronic "radiator" network. The pipework was arranged so that the heating system could be operated either as it existed originally or in the storage mode, in which case two of the five modular boilers were valved off. The two configurations were operated alternately (for 4-week periods), and their performances were carefully monitored over the 1985/86 heating season.

The storage system performed successfully with a 40% lower installed boiler capacity. Boiler cycling was reduced by a factor of 15 and the mean boiler-load factor rose from 37% to 70%. Analyses of results show that a 6% saving in annual fuel consumption was achieved by the storage system when compared with the highly efficient conventional system employing direct external compensation of the boilers. However all of this saving is attributable to the faster building-preheat achieved by the presence of the store as, surprisingly, the annual efficiencies of the two systems were the same (in contradiction to the findings of other trials) and the reasons for this are examined.

Where direct compensation is not possible, the demonstrated reduction in boiler cycling will lead to a further substantial efficiency advantage of at least 10%.

* = errartum

The principal potential benefits of incorporating thermal storage within central-heating systems have been described in reference 1 and may be summarised as:-

- Fuel savings, resulting from an increase in boiler efficiency, brought about by reduced boiler cycling and an increased boiler load factor.
- Additional fuel savings in intermittently-heated buildings, because they can be brought up to the required temperature more quickly.
- Lower installed boiler capacity being necessary.
- Improved, yet simplified, hot-water services for domestic applications.
- Competitive installation costs compared with conventional alternatives.

THE FIELD-TRIAL SITE

Spa Secondary School in Bermondsey, London is in a typical late-Victorian 3-storey school building, of thermally heavy-weight construction with very high ceilings and large windows. The total heated floor area is 1420m^2. It was selected as an appropriate site for a commercial-sector heat-storage field-trial because:-

- *The gas-fired heating system which was already installed was amenable for conversion to a thermal energy storage system.
- A modular boiler system existed there, and so part of the boiler capacity could be easily isolated or reinstated.
- The existing boilers had a low total thermal-capacity and were under direct compensating control, so that they might be expected to have a good part-load performance (cf. the Reigate system, ref. 2). Thus the behaviour of the storage system could be compared with that of a conventional alternative that might still be considered for a heating system being installed now.
- It had a well-defined occupancy pattern.
- Domestic hot-water was provided separately, and therefore the building's heating characteristics would not be corrupted.
- Its owners *(then the Greater London Council) and the school staff were cooperative, and even enthusiastic, about the proposed change.
- Last, but not least, there was enough space, with convenient access, for the introduction of a relatively-big storage vessel into the boiler-plant room.

British Gas undertook a preliminary study of the existing heating system to obtain design data (Gibson and Barnes (5)). From January to May 1982, the outside air, classroom, flow and return temperatures as well as the operation of each boiler were monitored.

The existing heating system comprised an old distribution system, but the boilers and controls had been replaced and updated in 1978. Five Hamworthy R320 modular atmospheric boilers (1), each with a nominal heat output rating of 75 kW, supplied a circuit of large cast-iron "radiators" connected to a single-pipe system made from mild steel. The boilers were controlled by an externally-compensated sequencer, in conjunction with a time switch and a building-condensation prevention (or 'frost') thermostat. The sequencer determined how many boilers should fire in order to achieve the desired compensated flow temperature, and ensured that only a single boiler (the "marginal" one) was cycling.

*
An optimal-start controller determined when to start the boilers firing to provide the initial store charge. The flow temperature to the radiators was regulated by mixing the flow from the boilers or store with the recirculated flow at a 3-way motorised valve, which was controlled by an external compensator. The boilers were fired whenever the store was in a charge mode. A thermostat at the bottom of the store determined when the store was fully charged, at which times the boilers (and boiler pump) were switched off and isolated by a motorised 2-way valve. Provided that the top thermostat was "calling" for heat, the start of the next charge cycle was triggered by a switch on the 3-way mixing valve, which was activated when the valve was almost fully open, so indicating that it was struggling to achieve the required flow temperature.

MONITORING

Fifteen parameters were measured at three-minute intervals and stored by* a data logger. Flow rates were obtained by magnetic flow meters: the temperatures, for estimating the efficiency of the system, were measured with platinum-resistance thermometers (PRTs): other heating-circuit temperatures were measured with chromel-alumel thermocouples: ambient air temperatures were measured with copper-constantan thermocouples. To detect transient phenomena during operation, the measurements were recorded at one-minute intervals for ten minutes after either of the water pumps was switched on or off. Additionally, the temperature profile down the vertical central axis of the store was determined every hour using ten chromel-alumel thermocouples. At roughly weekly intervals,* the tape was changed, the full tape processed on a Quantex decoder, and the week's data transferred, via a magnetic tape, to a VAX computer at Cranfield.

A standard and complete day was defined as one when (i) the heating system operated without problems or interference for the full 24 hours, (ii) simultaneously a full set of data was logged by the monitoring system, and (iii) the heating system started up and switched off at the normal times. Thus a day was non-standard if the heating was switched on for some evening activity or brought on by the frost thermostat. Non-standard days were excluded from the main analysis of the field-trial data. In the 1985/86 season, the monitoring period covered 36 weeks, 17 with storage and 19 with the conventional system. The final tally (excluding weekends) yielded 59 standard and complete days with storage and 77 with the conventional system, of which 9 and 16 respectively were Mondays.

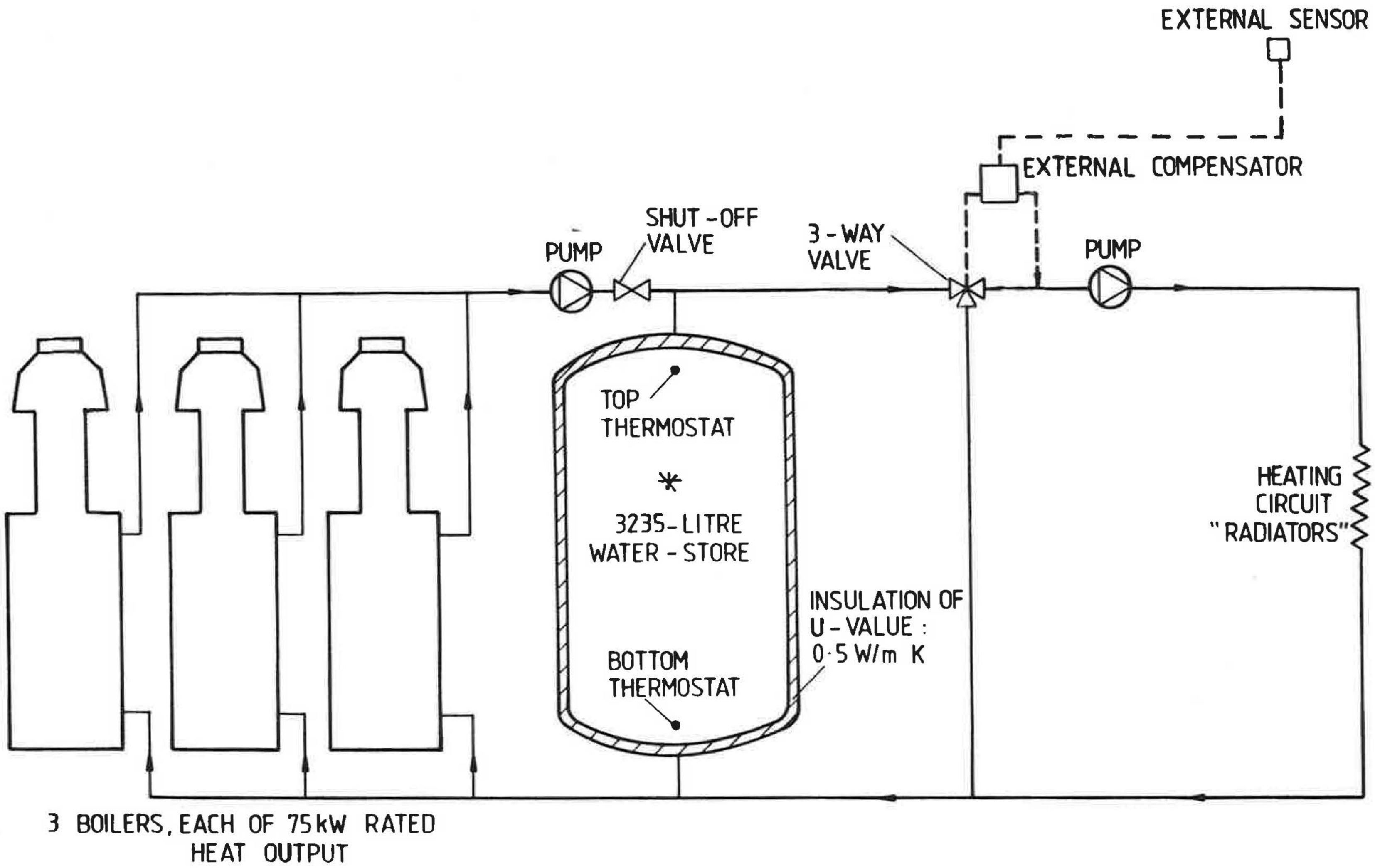

FIG.2 Simplified circuit diagram of the storage heating system