Paper No. 335

A Study of Thermal Properties of some of The Locally Avallable Building Materials to Improve The Summer Comfort in Residential Buildings*

BY

† Khan Muhammad Azam & Syed Irshad Husain

Introduction.

The climate of Northern Regions of West Pakistan is that of extremes. In winter people have to suffer from cold environment and in summer it is unbearably hot. The winter conditions can be taken care of by a fireplace or putting on extra clothing. It is the summer conditions which are depressingly intolerable. The summer heat causes decreased efficiency in work and retards mental activity. An important problem facing the engineer is to devise materials and design houses to give maximum comfort in summer. Air Conditioning is a luxury for the few. It is possible through proper design to increase the comfort in a building during the summer season. The subject needs considerable research and experimentation. It is the object of this paper to suggest means and arouse interest for improving the summer comfort in residential buildings. It also reports the results of thermal conductivity determinations made on locally available materials.

Thermal Properties of Building Materials.

Thermal properties of materials which determine their thermal behaviour when used in walls or roofs of buildings can be listed as follows :—

(1) **Thermal Conductivity (k).** This is the property of the material which reflects as to how much heat will be conducted through it relative to another material. For example, copper has a higher thermal conductivity than cork, while brickwork has thermal conductivity intermediate between these two materials. It may be defined as follows :—

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* The Experimental work was conducted in P.W.D., B & R Research Laboratory, Lahore

† Khan Muhammad Azam, I.S.E., B.Sc., Civil and Mech., Engg., (London), Dip., in Engg.; (Nottingham), Chief Engineer, Warsak Dam Project Organisation.

Syed Irshad Husain, B.Sc. Engg: (Pb)., M.Sc. (Harvard), J.M.A.S.C.E., General Manager, Packages Ltd., Lahore.

The thermal conductivity of a homogenous material is the rate of flow of heat, under steady conditions, through unit area, per unit temperature gradient in the direction perpendicular to the area. In English units it is expressed as Btu per sq. ft. per hour per °F for a thickness of one inch. Or,

$$k = \frac{Q.\ L.}{\theta \cdot A\ (t_1 - t_2)}$$

Where

Q = the total quantity of heat transferred (Btu).

θ = time (hrs)

A = Actual area normal to the path of heat flow (sq. ft.)

k = thermal conductivity.

t_1 = temperature of the hot surface (°F)

t_2 = temperature of the cold surface (°F).

L = Length of path of heat flow (inches)

(2) **Heat Capacity (c).** In the English system it may bo defined as the number of Btu needed to raise the temperature of one cubic foot of material through one degree Farenheit.

Water has a heat capacity of 62·5. Values for some other materials are given in table No. 1. Materials of high heat capacity can store a greater amount of "heat" or "coolness" for the same rise or fall in temperature. They will take a longer time to heat up or to cool down.

Material.	Specific Heat Btu./ lb/°F.	Weight in lbs per cft.	Heat Capacity (c) Btu./ cft/°F.
Water	1	62·5	62·5
Cast Iron.	0·1298	450	58·4
Brick work.	0·195	120	23·4
Deodar wood.	0·467	40	18·7
Glass	0·1977	162	32
Copper	0·0951	550	52·5
Coal.	0·2777	100	27·8

Table No. 1. Heat Capacity of different materials.

(3) **Thermal damping.** This is the property of a material constituting the wall or the roof to damp out the variations in the outside temperatures, thus making the inside tempe-

rature uniform. For given structure this property depends upon k and c and the thickness of the structure. Nearly one foot thickness of brick masonry considerably dampens out the day and night temperature variation (1).

(4) **Time Lag in Transmission of Heat.** The heat that strikes the external face of the wall is not transmitted to the internal face immediately. Depending upon the thickness, the thermal conductivity and the heat capacity (c), the instantaneous rate of heat gain on the internal face is some fraction of the instantaneous rate of heat entry on the external face at an earlier time. Materials with high thermal capacity have a higher time lag and smaller ratio of heat gain to the heat entry. Reduction of thermal conductivity reduces directly the ratio of heat gain to the heat entry. Time lag for some of the building materials is given in table No. 2. By looking at this table it will be clear why only insulation will not improve the summer comfort. For example, let us take a 12″ brick wall (overall thermal conductivity coefficiant — 0·31) and a 2″ wooden wall (overall thermal conductivity coefficient = 0·30). The former has a time lag of 8·5 hours while the latter has a time lag of only 1·3 hours. This means that 1·3 hours after the hot sun shines on the outside, the inside of the wooden wall will start getting hot while it will take 8·5 hours for the brick wall to start getting hot on the inside. It is on this account that wooden structures are not fit for our climate although their insulation values may be better than brick wall.

Material	Thickness (in.)	Time Lag (Hours)	Overall Conductance coefficient Btu. per (hr.) (sq. ft.) (°F).	Source
Stone	8	5·5	0·67	(3) A.S.H.V.E.
	12	8·0	0·55	,,
	16	10·5	0·47	,,
Solid Concrete	2	1·1	0·98	A.S.H.V.E.
	4	2·5	0·84	,,
	6	3·8	0·74	,,
	8	5·1	0·66	,,
	12	7·8	0·54	,,
	16	10·2	0·46	,,

Common Brick.	4	2·3	0·60	A.S.H.V.E.
	8	5·5	0·41	,,
	12	8·5	0·31	,,
	16	12	0·25	,,
Common Brick from Lahore Kiln.	3	1·5	0·61	B & R Research Laboratory Lahore.
	6	3—4	0·43	
	9	6	0·33	
	12	8—9	0·27	
Porous Brick with 10% sawdust.	3	1—1·5	0·43	B & R Research Laboratory Lahore.
	6	2—3	0·28	
	9	5—6	0·20	
	12	8	0·16	

Table No. 2. Time Lag in transmission of heat through building materials.

Thermal Conductivity Apparatus.

In order to determine the thermal conductivity of materials Guarded Hot Plate Apparatus was set up following the general principles as laid down in A.S.T.M. No. C 177-42 T. The general features of the apparatus are given in figure No. 1 and plates No. 1 & 2. The central section of the heating unit consists of a square central heater 16″×16″ (A). The heat flows from the specimen I to the cooling unit E. Two identical specimens (I) are put in the unit and tested simultaneously. The energy input in the central heater can be measured by means of an ammeter and a voltmeter and can be regulated by rheostats. The cooling units have cool water circulating through them. The guard plates which are connected to separate heat circuits are maintained at the same temperature as the central heater so that heat energy from the central heater does not travel towards the extremities of the specimen ; the idea being to have the heat flow at right angles to the surface of the specimen. The surface temperatures on the two sides of the specimens are measured by a set of 22 thermocouples. Knowing the heat input and the surface temperatures when a steady condition has been reached, the thermal conductivity coefficient (k) can be worked out.

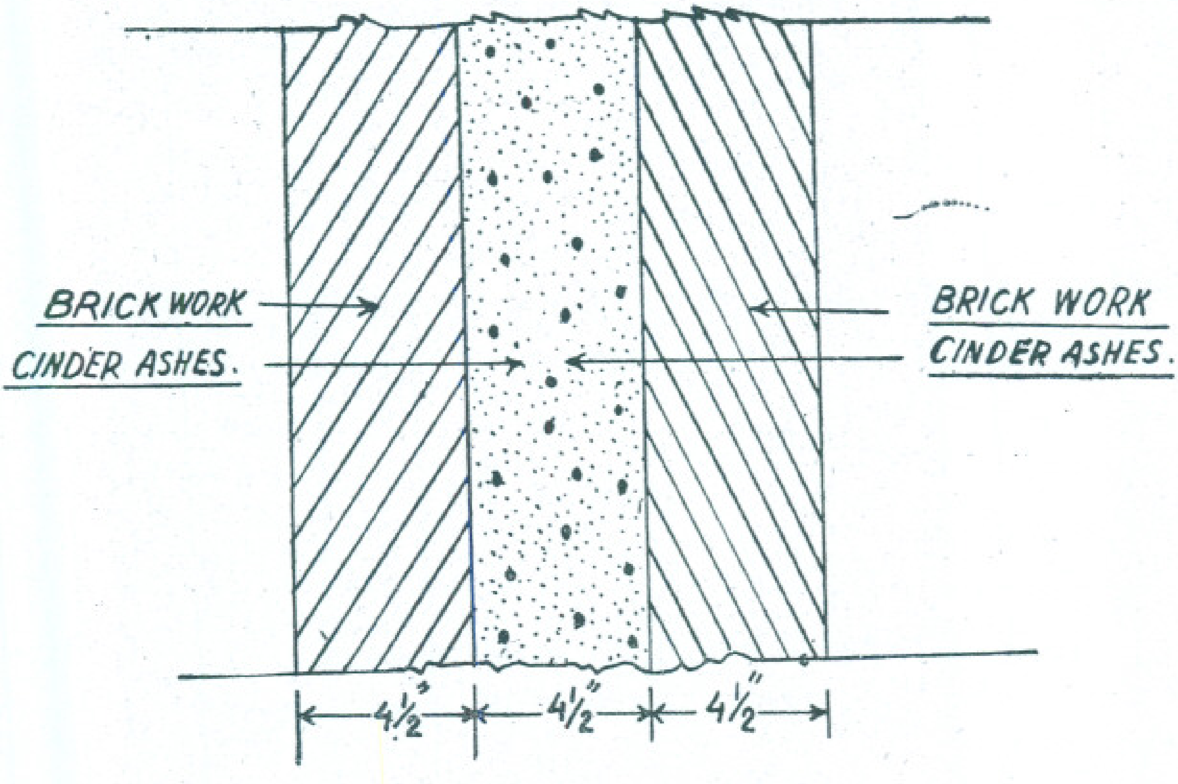
Thermal Conductivity of Materials. Table No. 3 gives the thermal conductivity determinations carried out on a number of materials obtained locally. For comparison some figures as obtained from the literature are also given.

S. No.	Material	k value Btu/(hour) (sft) (°F temp) (per inch thickness). As determined in the Laboratory.	As obtained from literature
1.	1 : 2 : 4 cement concrete.	11·9	—
2.	Surkhi (loose) (ground bricks)	2·36	—
3.	Cinder ashes.	1·51	—
4.	Saw dust.	0·41	—
5.	Rice husk cement blocks. (3 : 1 cement husk ratio by weight).	0·36	—
6.	Wood coal passing 1/2″ and retained 1/8″	0·35	—
7.	Ravi sand.	3·6	—
8.	Lahore soil, (loose)	2·1	—
9.	Bajri (gravel).		
	(i) Passing 3/4″ retained 1/2″—thickness of specimen=2″	2·95	—
	(ii) Passing 1/2″ retained 3/8″—thickness of specimen=2″	2·76	—
	(iii) Passing 1/2″ retained 3/8″—thickness of specimen=1″	2·24	—
	(iv) Passing 3/8″ retained 1/4″—thickness of specimen=1″	2·48	—
	(v) Passing 1/4″ retained 1/8″—thickness of specimen=2″	2·87	—
10.	Bricks :—		
	(i) Katcha bricks (unburnt clay bricks).	4·0	—
	(ii) Ordinary bricks.	4·5	—
	(iii) Porous bricks with 10% sawdust.	2·3	—
11.	Maples or oak.	...	1·15
12.	Pine or Fir.	...	0·8
13.	Cardboard.	...	0·3
14.	Glass wool.	...	0·27
15.	Cork board.	...	0·3

Table No. 3. Thermal Conductivity of Building Materials.

Cinders Ashes.

Cinder ashes are a cheap by-product and can be effectively used for improving the insulation characteristics of wall structures. The exterior walls of Pre-Cadet College Hassan Abdal have been filled with 4·5" of cinder ashes as shown in figure No. 2.



Eigure No. 2. Walls filled with cinder ashes.

The k value works out to be 1·51 which means that 4½" cavity filled with these ashse will give the same thermal insulation as 15" of brick work. Therefore, these walls although being 13½" thick will give the same thermal protection as provided by 24" thick brick wall.

In cubic content the cinder ashes are cheaper as compared to B. B. in 1 : 5. The cost of ashes brought on the site of Pre-Cadet College is Rs. 21/- per % cft. Allowing Rs. 4/- per % cft as the cost of filling the cavity, the cost of filled cavity will be Rs. 21 + Rs. 4 = Rs. 25 per % cft. The cost of B.B. in 1 : 5 will be Rs. 75, which is considerably higher than Rs. 25.

Settlement. After the cavity walls have been filled no appreciable settlement can be expected. An experiment was run in which a 2′ high column of ashes was vibrated for a period of four hours. At the end of this period only 2% settlement occurred.

Settlement due to Moisture. A 15″ high jar was filled up with ashes. The tamping was done during the process of filling the jar. Water was added to the jar from the top and was allowed to saturate the material. After 24 hours, settlement of about 3/8″ had taken place which amounts to 2·5% settlement. It is not expected that the ash filled cavity will be inundated with moisture to the extent of saturation. The settlement observed is not enough to bar the use of ashes.

Rice Husk Cement Blocks.

Rice husk is a material cheaply available in plenty in the rice growing belts of Pakistan. Blocks of size 2′ x 2′ x 1″ were prepared using 3 : 1 ratio of cement to rice husk by weight. The thermal conductivity of these was determined and found to be 0·36. For the comparison k value for cork and wood is 0·3 and 0·8, respectively. This means that rice husk block is a good insulating material. The structural strength of rice husk blocks is low and therefore they cannot be made to bear any load.

Porous Bricks Moulded by Addition of Sawdust.

Bricks were moulded by adding increased quantities of saw dust to clay, the aim being to reduce the thermal conductivity with the air voids. Local clay was used, the properties of which are listed in table below :—

Liquid Limit :	32·25
Plastic Limit ,	21·35
Plasticity Index	10·90
Sand Content :	3·0%
Salts :	·1%
Lime :	2·5%

It was a clay of type normally being used for brick making purposes in Lahore area. The saw dust was of deodar from a local saw mill. The saw dust and clay were mixed dry and then enough quantity of water was added to facilitate moulding. Bricks were moulded by an experienced brick moulder who was instructed to see that the process was similar to the one in the field and that no special care was to be exercised.

The saw dust was added on volumetric basis in proportions of 5, 10, 15, 20, 30, 40 and 50%, After moulding the clay bricks were allowed to dry in the shade for about 4 hours and then exposed to sun-rays. The moulding process was done in the month of May when the hot dry winds were prevalent. The hot dry winds, if allowed to play on freshly moulded bricks, cause cracking on the surface. However, in the case of these bricks no cracking occurred. The presence of saw dust prevents cracking. The firing was done in a kiln at Baghbanpura using coal at the rate of 25 tons per lac of bricks along with ordinary bricks being manufactured. Fifty bricks for each item of the series were placed in the kiln suitably marked and were taken out when the kiln was unloaded.

Thermal Conductivity Coefficient (k) of Porous Bricks.

Thermal Conductivity Coefficient determination were made on bricks moulded with varying percentages of saw dust. The results are tabulated in table No. 4. It will be seen that ordinary brick has a k value of 4·5. The k value drops suddenly on addition of 5 to 10% saw dust and then it is more or less constant at 2·3 upto addition of 30%. On addition of higher quantities of 40 and 50% the k value drops to 0·96 and 0·85, respectively. Thus, by adding 10% saw dust the thermal conductivity is reduced from 4·5 to 2·3. Addition of 10% saw dust is quite convenient and the reduction in the k value achieved is quite appreciable. Therefore, 1″ thicknest of porous bricks with 10% saw dust addition will provide the same thermal insulation as nearly 2″ of orddinary brick $\left(\frac{4{\cdot}5}{2{\cdot}3}=2 \text{ nearly}\right)$. In other words, 4½″ thick porous brick provides insulation equivalent to 9″ of ordinary brick. Therefore, by using 4½″ thickness of porous brick in wall thickness of 9″, from a thermal point of view, a wall of 13½″ thick insulation is obtained.

Material.	Weight in lbs/cft.	Water Absorption % by weight.	Compressive Strength lbs/sq. in.	Thermal Conductivity Coefficient(k) in Btu/(hr) (sq. ft.) (°F per. in.)
Ordinary Bricks.	112·1	10·4	2275	4.5
5% by volume Saw dust Bricks.	85·4	28·9	1470	2·57
10% by volume Saw dust Bricks.	82·9	31·7	1089	2·3
15% by volume Saw dust Bricks.	80·2	30·5	1165	2·28
20% by volume Saw dust Bricks.	78·6	27·9	1071	2·33
30% by volume Saw dust Bricks.	77·1	26·3	1195	2·3
40% by volume Saw dust Bricks.	67·7	37·0	754	2·22
50% by volume Saw dust Bricks.	57·3	52·1	255	1·9

Table No. 4. Showing the properties of porous bricks prepared by adding varying quantities of saw dust.

cavity, the cost of filled cavity will be Rs. 21 + Rs. 4 = Rs. 25 per % cft. The cost of B.B. in 1 : 5 will be Rs. 75, which is considerably higher than Rs. 25.

Settlement. After the cavity walls have been filled no appreciable settlement can be expected. An experiment was run in which a 2′ high column of ashes was vibrated for a period of four hours. At the end of this period only 2% settlement occurred.

Settlement due to Moisture. A 15″ high jar was filled up with ashes. The tamping was done during the process of filling the jar. Water was added to the jar from the top and was allowed to saturate the material. After 24 hours, settlement of about 3/8″ had taken place which amounts to 2·5% settlement. It is not expected that the ash filled cavity will be inundated with moisture to the extent of saturation. The settlement observed is not enough to bar the use of ashes.

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Table No. 4. Showing the properties of porous bricks prepared by adding varying quantities of saw dust.

Structural Aspects of Porous Bricks. The crushing strength of ordinary bricks moulded in Lahore area varies from 2000 to 2500 lbs per sq. inch (128 to 161 tons per sq. ft.) As per the Punjab P.W.D. Specifications (1936) walls in cement mortar are designed for a compressive strength of 8 tons per square foot while walls in weaker mortars are designed at lower values. Therefore. an appreciable decreased strength of bricks is permissible without endangering the stability or the strength of the structure. 10% saw dust porous bricks give a compressive strength of 1100 lbs per sq. in. (70 tons per sq. ft.). Allowing a factor of safety of 4 the bricks will have a safe compressive strength of 17·5 tons/sq. ft. which is considerably higher than than the figure of 8 tons/sq. ft. used in the design. The bricks can be used separately or in combination with ordinary bricks in the wall structures.

Fuel Consumption. Normally for firing one lac (1,00,000) bricks, 25, tons (Rs. 1250) coal of 10,000 Btu per lb. calorific value is needed. Addition of saw dust to bricks amounts to addition of fuel. It also reduces the bulk of the clay to be fired, thereby reducing the fuel consumption. Saw dust will have an average calorific value of 8,000 Btu per lb. For one lac bricks with 10% saw dust we need 19 tons of coal (Rs. 950) and 4·3 tons saw dust (Rs. 240)—the total cost of fuel being Rs. 1190 against Rs. 1250 using coal only. So we actually save on the cost of fuel. Possibly the cost in the two cases will be equal.

There is considerable scope for investigatlon on porous bricks. Research can be conducted by preparing and testing bricks with addition of coal dust, corn straw (bhusa), etc. This might show further improvement in the quality of bricks obtained.

Aids to Summer Comfort.

Some aspects which materially affect the summer comfort in residential buildings are being discussed.

Cooling Due to Shading. 420 Btu per hour per sft. at normal incidences are received by the earth surface from solar radiation. A part of this is absorbed in the atmosphere by the gases and dust particles. In Lahore, in the month of June when the altitude of the sun is 80°, about 300 Btu per hour per sft. at normal incidence will be received. In the early morning when the angle of incidence is 10°, 120 Btu received and ssmilarly in the evening the amount of solar heat is reduced. In between these timings an intermediate intensity of solar radiation will be received.

If the sun rays fall on a roof or a wall, the ontside surface temperature of the wall will be increased. This will increase the mean temperature of the wall structure and to some extent the inside room temperature. The effective temperatuae which represents the combined effect of the sun rays, is termed as Sol-Air Temperature. As an example, in

TABLE

The Heat Gains in a When the Sun Rays

Description		Northern Wall. Btu.	Western Wall. Btu.
1. Heat Gained Due to the Effect of Outside Hot Air Alone at Temp: Of 105°, i.e., If Shading is Provided.		22,500 Btu.	22,500 Btu.
2. Heat Gained Due to the Combined Effect of Outside Hot Air at Temperature if 105°, and the Effect of Sun.		22,500 ,,	39,050 ,,
3. Extra Heat Gained Due to the Sun Rays Striking the Structure.	Btu.	In Northern Hemi-Sphere shading of northern walls does not make much difference.	16,350 ,,
	% Increase		77%
4. Sol-Air Temperature.		105°F Average For 12 Hours.	136°F Average For 6 Hours.

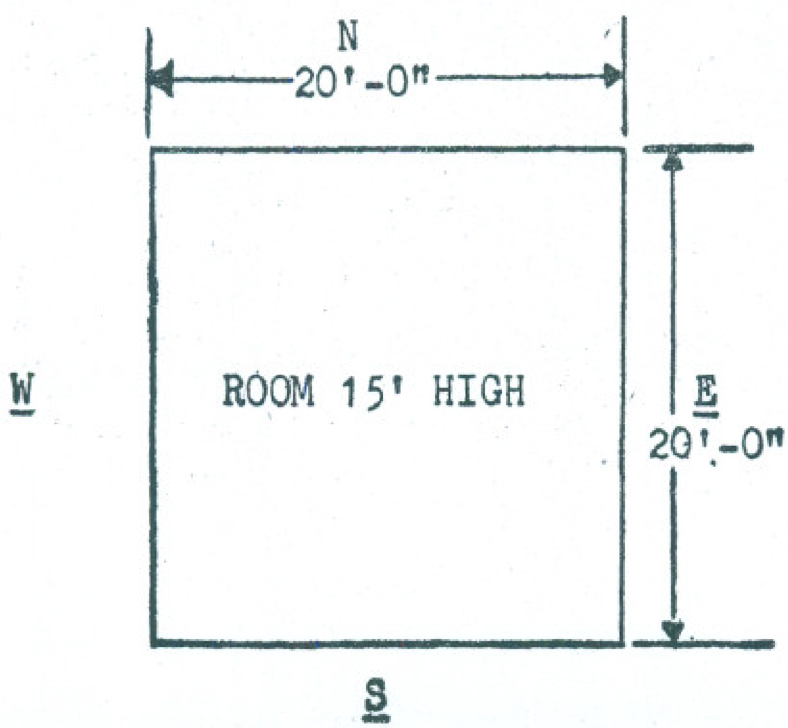
NOTES :—

1. Room Size 20′ × 20′ × 15′ high, exposed on all sides.
2. Temperature of room inside = 85 °F.
   Out door temperature = 105 °F.
3. Sun conditions of month of June assumed when sun is at an altitude of about 80° at Lahore.
4. Walls assumed to consist of $13\frac{1}{2}''$ of brick masonry Thermal Conductance (U) = 0·312 Btu/hr./°F/in.
   Roof assumed to consist of 6″ of R.C.C. with 4″ Earth cushion on top of it, with $1\frac{1}{2}''$ tile placed on it Thermal Conductance (U) = 0·39 Btu/M./°F/in.

No. 5.

Room When Shaded or Shine on it Directly.

Eastern Wall. Btu.	Southern Wall. Btu.	Roof.	Total Heat Gains From Walls & Roof
22,500 Btu	22,5000 Btu	28,000 Btu.	118,000 Btu.
37,650 ,,	36,000 ,,	83,000 ,,	219,000 ,,
15,150 ,,	13,500 ,,	55,000 ,,	101,000 ,,
67%	60%	196%	85%
132°F Average For 6 Hours.	117°F Average For 12 Hours.	144°F Average For 12 Hours.	



the month of June in Lahore for 1 o'clock the outside air temperatura is 105°F. The Sol-Air temperature of the masonry surface placed at right angles to the incident sun rays would be 180°F. The Sol-Air temperature for the same time and conditions for southern masonry walls will be 117°F and the horizontal roof 170°F.

It is, therefore, evident that the shading of the walls and the roofs by some means will be effective in reducing the temperature indoor. In table No. 5 heat gains through the four walls and roofs of a room have been worked out with and without the shading. The sun conditions of month of June have been taken into consideration. The walls consist of $13\frac{1}{2}''$ of brick masonry with the thermal conductance (U) of 3·312 Btu per hour per °F gradient. The roof is made up of 6" of R.C.C. with 4" earth cushion on top, with $1\frac{1}{2}''$ tile placed on it, giving the thermal conductance (U) of 0·39 Btu per hour per °F. It will be seen that a total of 85% additional heat or 101,000 Btu. are absorbed due to the effect of sun rays falling directly on the structure. This much heat raises the temperature of the materials comprising the walls and the roof through 5°F. This rise in temperature is quite appreciable. The western and eastern walls show increased heat absorption of 77% and 67%, respectively, although sun shines on these for a period of six hours only. The southern wall on which the sun shines all through the twelve hours has an increase of 60% only. This is due to the fact that the angle of incidence on western and eastren walls is on the average 45° while on the southern wall it is 10° throughout the day. The roof shows an increase of 196%, indicating that a major portion of heat is absorbed from the roof and protecting the roof by suitable means from the sun rays will greatly improve conditions.

Now, that we have seen the importance of shading quantitatively we have to look for the ways and means to provide the shading.

(a) Northern Walls. In the zones, north of Tropic of Cancer it is not required to shade the northern walls as the sun rays cannot fall on these.

(b) Eastern and Western Walls. It will be necessary to provide deep verandahs on both the eastern and western sides of the house in order that only the early morning or the late evening rays of the sun can strike walls at a time when their intensity is the lowest. Table No. 6, obtained from the A.S.H.V.E. Guide indicates the intensity of solar radiations at various altitudes of the sun. It will be seen from this table that the intensity of solar radiation in the early morning and late evening will be lower.

Solar Altitude Degree.	Btu per (Hr) (Sq. Ft.).
5	65
10	122
15	165
20	196
25	219
30	234
35	245
40	253
45	260
50	266
60	276
70	283
80	289
90	294

Table No. 6. Values of direct solar radiation received at normal incidence at the earth's surface.

Sun shades on these walls will be impracticable due to the fact that they have to project out a good 10 feet to provide the required protection. Alternately on the eastern and western sides of the building bath rooms, dressing rooms and storage rooms be provided which will get comparatively warmer but since they are used only over shorter lengths of time the discomfort will be momentary.

(c) **Southern Walls.** Table No. 5 shows that when exposed to the sun, the southern wall absorbs 36,000 Btu. Under the same condition eastern and western walls absorb 37,650 and 39,050 Btu, respectively. This shows that contrary to the normal belief, during the month of June, the southern wall absorbs slightly lesser heat as compared to eastern or western walls. Therefore, the eastern and western walls have to be given the same attention in providing suitable shade protection as the southern wall.

In northern regions of West Pakistan in all the buildings effort is made to provide shading on the southern walls by providing verandahs. Many a time verandahs are built on the south even though they are not deemed essential for the purpose of accommodation. In such cases long projecting sun shades as indicated in figure No. 3 are suggested. The length of the shade will be given by the equation.

$$L = H \tan \theta$$

where

L = length of the sun shade (or the projection)

H = height of wall that needs to be shaded.

θ = angle between the sun rays and the wall on a certain day in the year.

The figure shows an angle of incidence of sun rays on a southern 12′ high wall in Lahore for different dates of the year. It will be seen that the sun shade 2·11″ long will completely shade the wrll on 22nd June. On 22nd September and 22nd March when the sun is shining vertically on the equator and the angle of incidence on the wall is $31\frac{1}{2}°$, projection of the sun shade needed is 7·35. The periods during which the shading is most desirable are between 15th April and 1st of September and the projection needed for this period is 5·67′ or say 6′ as indicated by BD. A 6′ projection can be easily and economically placed at the ceiling level and will provide shading of the wall all through the hot months. Alternately, two sun shades each 3′ long be provided, one at the ceiling level and the other at the window sun shade level, as indicated by lines CD and EF.

The altitude of the sun in winter is very low as indicated by the sun rays for the 22nd of December. This means that during winter sun shade will admit the sun rays into the window to heat up the room. Thus, by providing the sun shade we are shading off the wall in summer and getting the benefit of sun rays in winter.

(d) Roof. Total heat gains for walls and roofs for the example under reference are 101,000 Btu. Out of these the roof alone absorbs 55,000 Btu, meaning thereby, that more than half of the heat gains are from the roof alone. The shaded roof absorbs 28,000 Btu while the unshaded roof absorbs 83,000 Btu, showing an increase of 196%. This is why the rooms with a storey on the top are cooler. The indication is that the summer comfort can be greatly improved by shading the roof.

Shading of the roof may be done by placing bricks on the roof and spreading Sirkanda (reeds) on their top. It is essential that good ventilation in the cavity between the Sirkanda and the roof top is provided, otherwise the temperature cf the air in the space will rise to the sol-air temperature and the benefit derived out of shading lost. People have tried placing "Gharas" (clay pots) on the roof and have reported cooler conditions in the room. Any other method adopted for providing the shading will prove equally effective. It is suggested that improvement in the thermal insulation of the roof will be more beneficial than the thermal insulation of the walls.

Use of Nightly Cool Air.

In figure No. 4 a plot has been made of maximum and minimum temperatures and relative humidity throughout the year at Lahore. In the months of March, April, May and upto 15th June the temperature difference between the night and day is nearly 30°. The highest temperature occurs at 2 P.M. and lowest at 3 A.M, The house with very thin structure will get heated upto the highest temperature at the noon time which may be of the order of 100 to 110°. The aim is to get

Solar Altitude Degree.	Btu per (Hr) (Sq. Ft.).
5	65
10	122
15	165
20	196
25	219
30	234
35	245
40	253
45	260
50	266
60	276
70	283
80	289
90	294

Table No. 6. Values of direct solar radiation received at normal incidence at the earth's surface.

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Use has to be made of the cool air of the night which has a temperature of between 60 to 70°F. This ean be done by keeping the windows and Roshandans (ventilators) open at night time and admitting the night air into the room. The hot air in the room has lower density than than the cool air outside and a current of air is established - cool air comes through the doors and windows and goes out through the Roshandans. The Roshandans may therefore be placed as high up as possible near the roof to give a maximum column of hot air.

Actual observations were taken on a room with 13½″ exterior walls with 2″ air cavity. The doors which extended from roof to the floor were opened from 6 p.m. to 6 a.m to let the cool air circulate through the room at night. The observations were taken in the months of April and May and the results for 6 typical days are given in table No. 7. The temperature of the *night before* is reflected in the maximum temperature recorded during the day. A cool night is followed by a cool afternoon and a warm night by a warm aftetnoon.

For example on 27-9-52 the previous night was warm having a minimum temperature of 80° and the day's temperature stayed high up between 88° and 89°. Although it was a relatively cool day having a maximum outside temperature of 100° yet the afternoon temperature rose to 89°. The following night i.e., in the early hours of 28-4-52 the outdoor temperature fell to 73° and the subsequent afternoon had temperature between 84° and 87° Although the outside maximum temperature rose to 108° i.e. 8° higher than the previous day yet the maximum temperature in the room was 87° being 2-5° lower than *the* previous. Similarly, low temperature of 70° in the early hours on 5-5-52, depresses the subsequent day temperature to 82-83° and the high night tempeɹgture 183° in the early hours of 9-5-52, raises the subsequent day temperature to 88° - 89°—6° higher than the previous day. The same

* Temperatures are in Degrees Fahrenheit.

trend is reflected in the readings for 12-5-52. and 17-5-52.

Date	Minimum outdoor temperature recorded in the night before (at about 5 A.M.) °F	Minimum outdoor temperature recorded in the night before (at about 5 A.M.°F	Maximum Outdoor Temperature.
27-4-52	80	88-89	100
28-4-52	73	84-87	107·5
5-5-52	70	82-83	97
9-5-52	83	88-89	103·5
12-5-52	77	91-93	118
17-5-52	82	95-97	117

Tablc No. 7. Relation between the night outdoor temperature and room temperature in the afternoon-.

The Use of Attic Exhaust Fan. Alternately, forced ventilation may be provided in the building by suitably interconnecting the rooms and providing an exhaust fan or what is termed as Attic Exhaust Fan to blow out the nightly air to be replenished by cool air. Investigations have been carried out in the U.S.A. on the the use of these fans and the method has won popularity there and in Australia.

In Lahore on experiment was conducted in a bungalow built in Gulburg with an exhaust fan. Lowering of afternoon temperature to extent of 5 to 10°F was noticed in the afternoon time of summer months of April, May and June when the night were apreciably cool.

Air Ghanges and Extent of Cooling. The question arises as to how many air changes should be provided for getting best results. Tests were conducted in the U.S,A. at Atlanta, Georgia (latitude 33½°N which is comparable with the latitude in Lahore of 31½°N). At a rate of ventilation of 45 air changes per hour during the night the room was 5 to 8° cooler than the house which was cooled by natural ventilation only. The outdoor night temperature was 18° below the maximum outdoor temperature during the day. The single-storey houses made up of frame structures could be cooled down to within 2 °F of the outside night temperature.

Tests at Illinois show that at a rate of 17 air changes per hour with the fan operating during the night the indoor temperature dropped 2 °F for every 3 °F drop in outside temperature. When natural ventilation was depended upon the indoor temperature fell by 1 °F fcr 3° fall of outdoor temperature. It may be expected that in Lahore where the difference in the maximum and minimum temperature is 30°, by suitable rates of air changes, temperature may be dropped to within 5° of the outside night temperature.

Various authorities have conducted experiments with air change rates of between 17 to 120 per hour. These indicate that effective results could be obtained at rates of 15 to 33 air changes per hour. At Lahore, in a suitably ventilated room with windows and ventilators, by the stack effect alone between 10 to 15 air changes per hour may be obtained The fan should be put on as soon as the outside air temperature falls below the room temperature. This, in Lahore, would occur in the summer months between 6 P.M. and 6 A.M. The doors, windows and ventilators should be closed in the morning so that the hot air cannot enter in. It is suggested that instead of connecting the whole house to the fan only those rooms be connected which are occupied during the afternoon by the family.

Effective Depth of Walls Structures for Storing the "Coolness".

Prof. Wilburn C. Thoburn (1,2) has carried out theoretical studies and he suggests that walls of the room built with brickwork get cooled to an extent of 3" from inside by the cool air circulating through the room and the effect beyond 3" is insignificant.

Figure No. 5 indicates the travel of heat in a wall built with ordinary bricks. One face of the wall was heated and the other kept at the room temperature. It will be seen that in eight hours although heat penetrated to an extent of 9", yet the prominent heat storage effect was upto 4·5" only. Therefore, for providing "coolness" storage the inner 4·5" wall thickness will have to be looked into and suitable material provided for it. We may, therefore, provide as exterior wall 13½" thick brick staucture. The outer 9" be made out of the porous bricks so that they reduce the quantity of heat inflow into the building. The inner face be made with ordinary bricks which will cool down at a higher rate as compared to porous bricks. With their higher thermal capacity they will store a greater amout of coolness.

The interior walls should be of 9" size made up of ordinary bricks to receive the night coolness. These walls are not expected to retard the heat inflow. They will be useful in producing the cool conditions in the afternoon.

Summary

The general problem of the country is protection against the summer heat and the houses have to be designed in a way to provide maximum comfort in the summer months. The structural materials of the building play a very important part in determining the summer comfort provided by the building. Study has, therefore, been carried out at the P.W.D. B & R Research Laboratory Lahore to find out the thermal conductivity coefficient for the locally available materials so that optimum benefit can be obtained at the minimum cost. The

materials like wood charcoal, cinders, cement and rice husk blocks have been put to test. Bricks have been prepared by adding saw dust to clay and then firing it. These bricks show a considerable reduction in the thermal conductivity coefficient as compared to the ordinary bricks. The bricks with 10% saw dust added have value of k reduced to half of that for the ordinary bricks. The structural strength is also reduced to half but still the brick is strong enough to be used for construction purposes.

For improving the summer comfort of the houses shading of the roofs and walls is very desirable. By letting the cool night aircirculate through the room at night subsequent afternoon can be made cooler by about 5 to 10° F. For this installation of an exhaust fan may be necessary.

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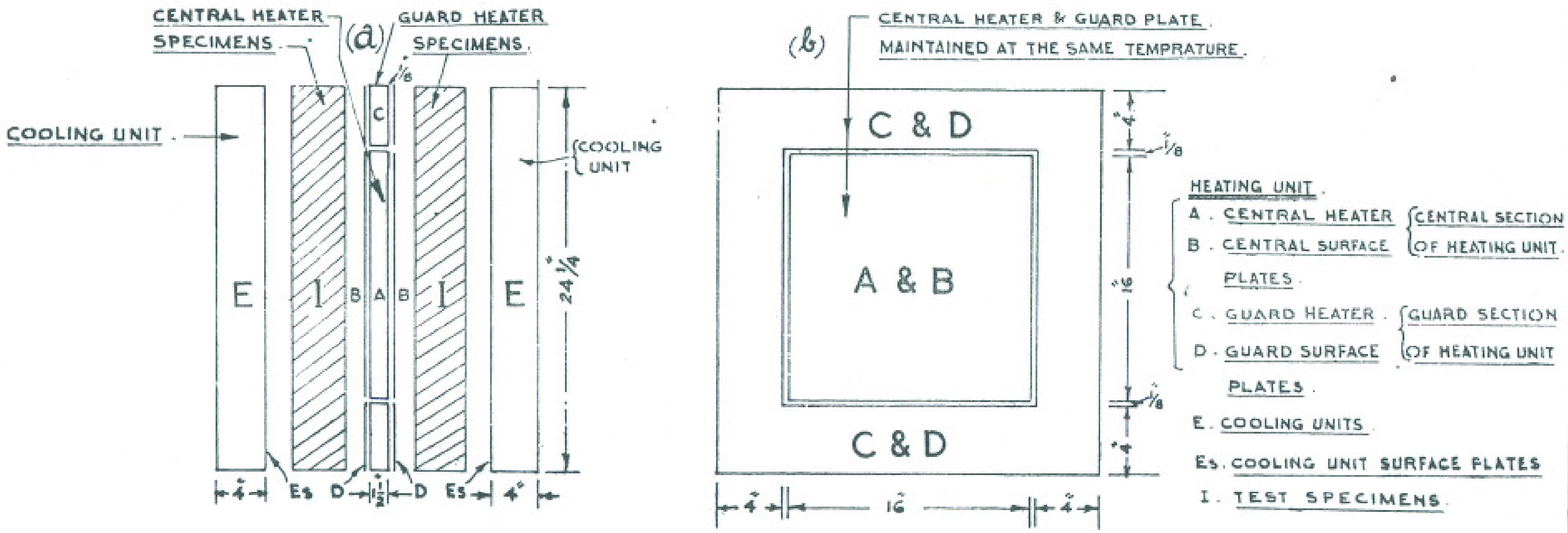
FIG. NO. 1.

GAURDED HOT PLATE THERMAL CONDUCTIVITY DETERMINATION UNIT.



(a) FEATURES OF THE GUARDED HOT PLATE WITH SPECIMENS UNDER TEST & COOLING UNITS.

(b) HEATING UNITS.

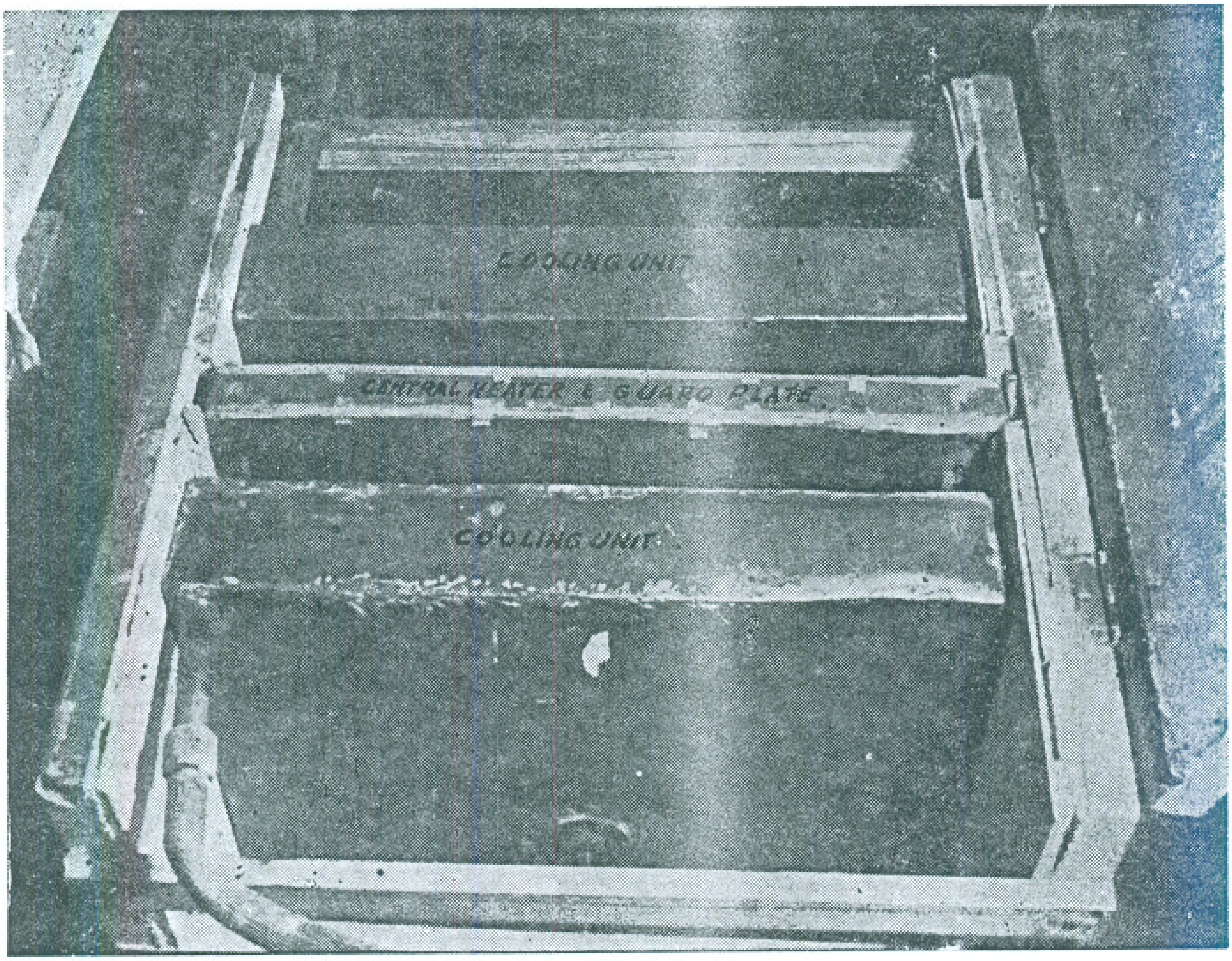


PLATE NO. 1 ***Specimen Box. Showing Central Heater, guard plate and cooling units of Thermal Conductivity Apparatus.***

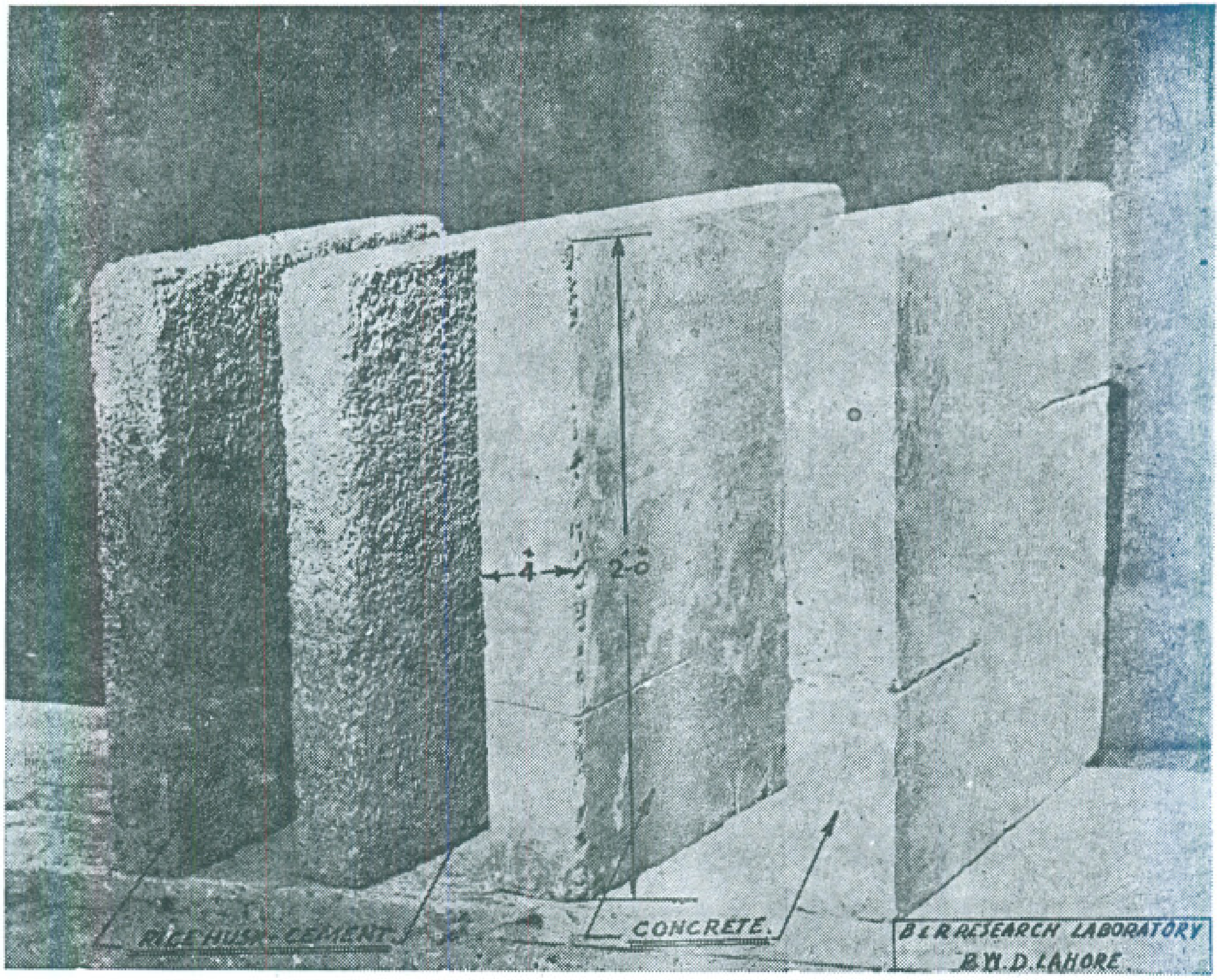
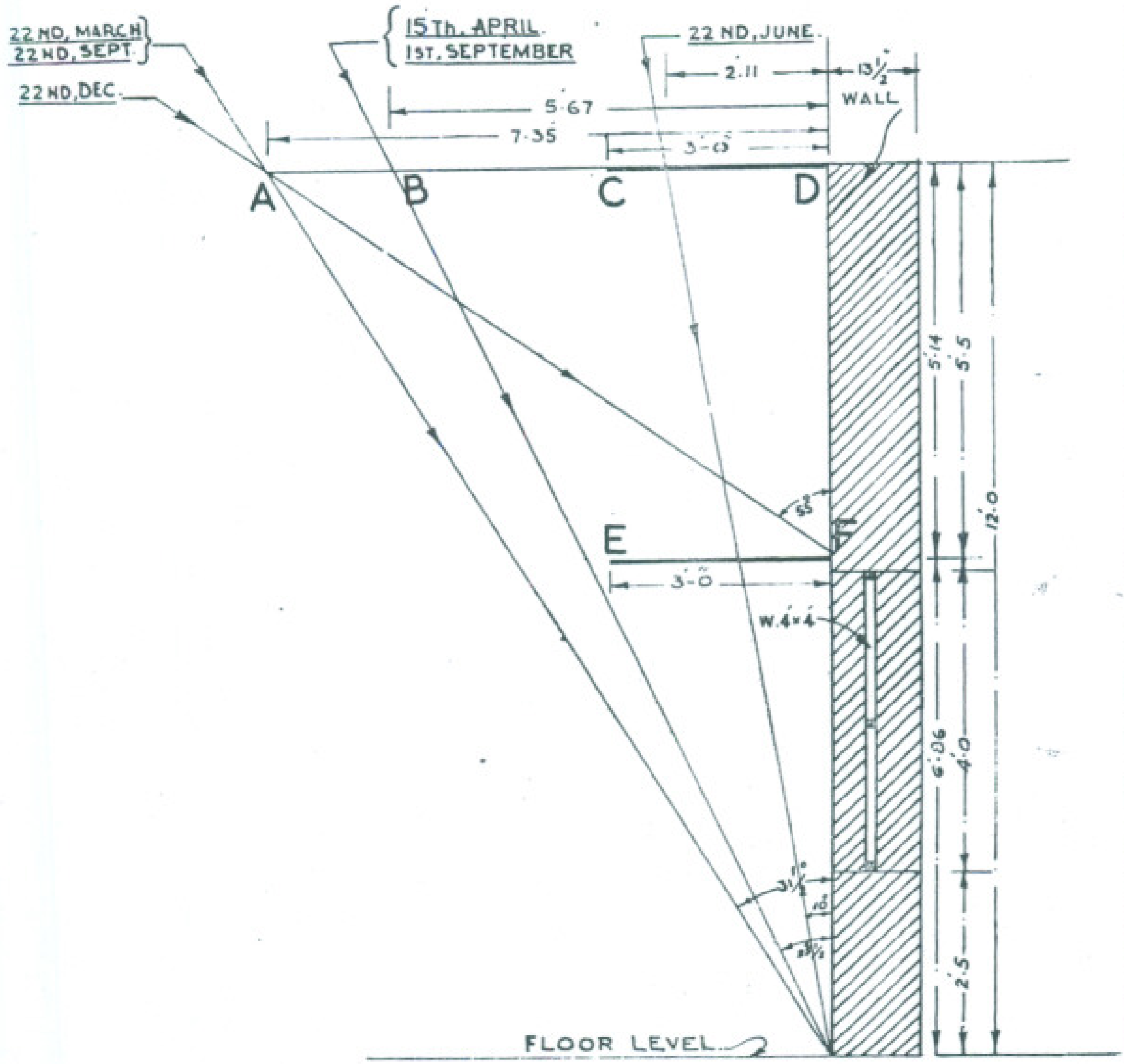


PLATE NO. 2. ***Specimens for Determination of Thermal Conductivity.***

FIG. NO. 3.



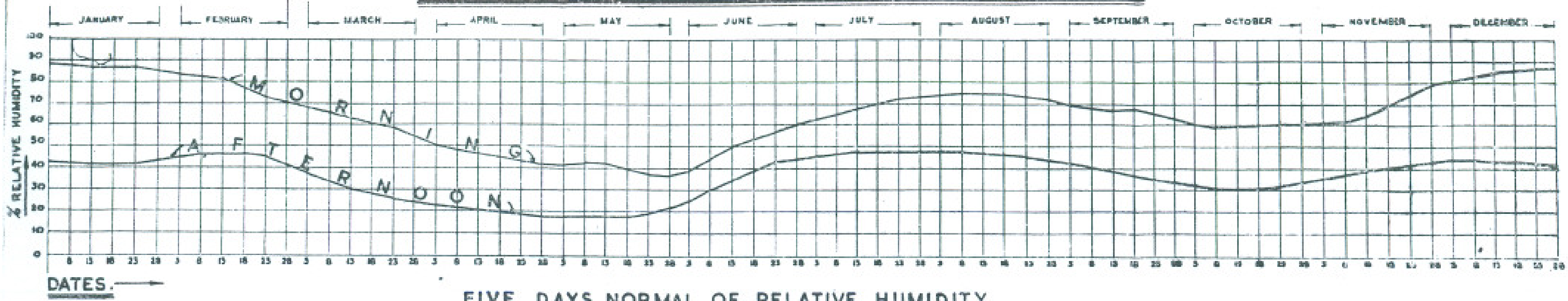
THE ANGLE OF INCIDANCE OF

SUN RAYS ON DIFFERENT DATES ON A 12' HIGH

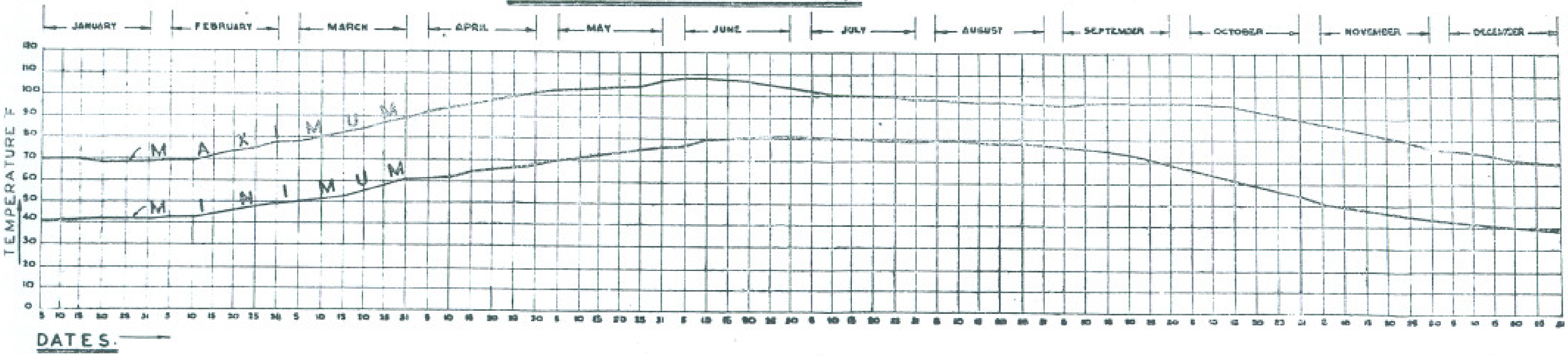
SOUTHERN WALL AT LAHORE LATITUDE 31½° N.

FIG. NO. 4.

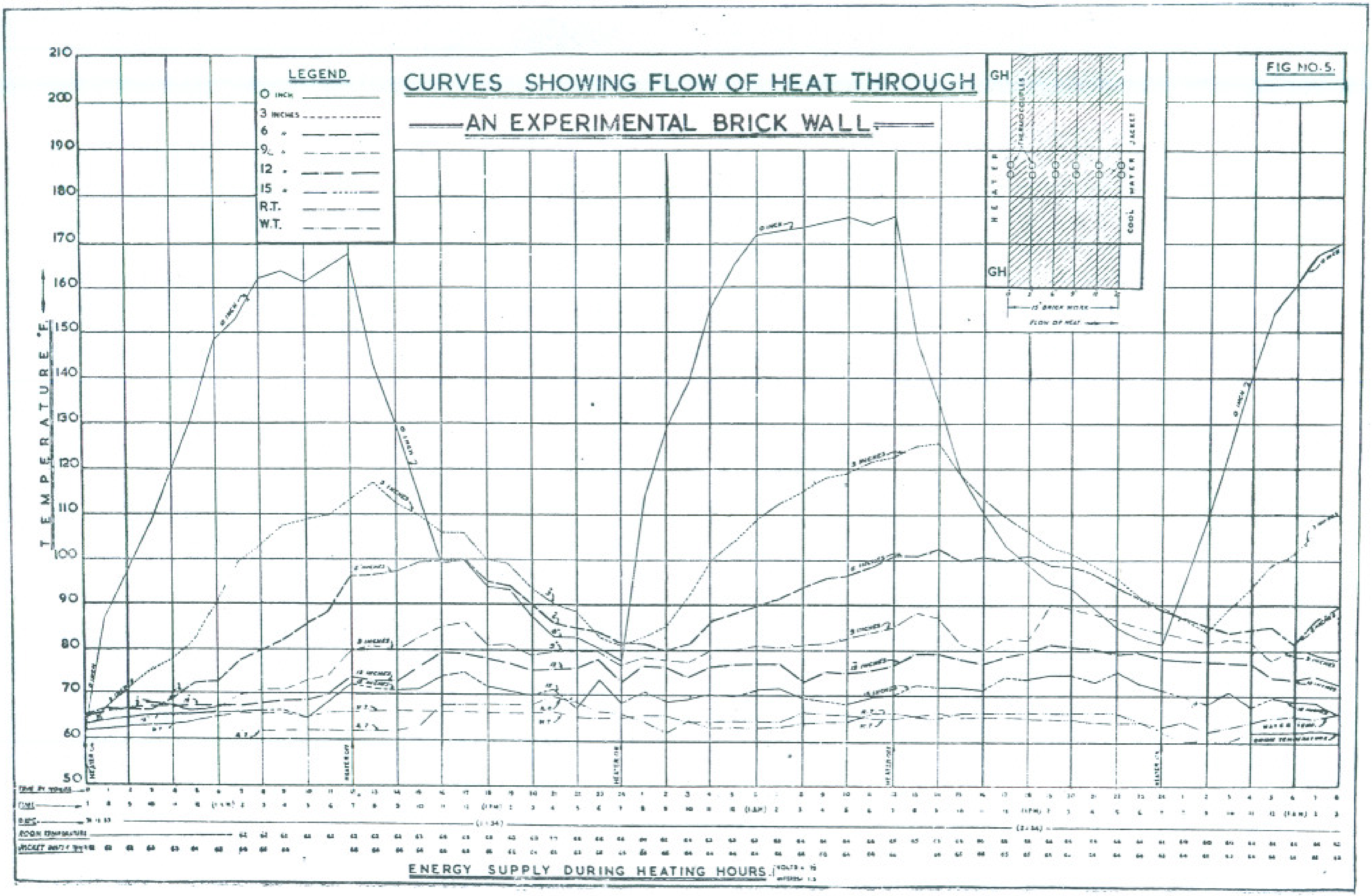
PLOT OF AVERAGE TEMPERATURE AND RELATIVE HUMIDITY FOR LAHORE.



FIVE DAYS NORMAL OF RELATIVE HUMIDITY
AT 9:30. HRS.P.S.T.(0230 HRS G.M.T.)&
AT 16:30.HRS. P.S.T.(1130 HRS. G.M.T).



FIVE DAYS NORMAL OF MAXIMUM & MINIMUM TEMPERATURE.


CURVES SHOWING FLOW OF HEAT THROUGH
AN EXPERIMENTAL BRICK WALL
FIG NO. 5.
LEGEND
O INCH
3 INCHES
6 "
9½ "
12 "
15 "
R.T.
W.T.
TEMPERATURE °F.
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
GH
HEATER
THERMOCOUPLES
COOL WATER JACKET
15" BRICK WORK
FLOW OF HEAT
HEATER ON
HEATER OFF
ROOM TEMPERATURE
ENERGY SUPPLY DURING HEATING HOURS