NATIONAL BUREAU OF STANDARDS REPORT

10 392

U.S./FRENCH COOPERATIVE PROGRAM ON BUILDING TECHNOLOGY (ENVIRONMENTAL ENGINEERING)

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.
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NATIONAL BUREAU OF STANDARDS REPORT

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U.S./FRENCH COOPERATIVE PROGRAM ON BUILDING TECHNOLOGY (ENVIRONMENTAL ENGINEERING)

by
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U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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Abstract

The U.S.-French cooperative work in the field of Environmental Engineering initiated during and after the visit of the author to the Centre Scientifique et Technique du Batiment (CSTB) is reported. The topics covered in this report are:

1. Comparative results of digital and analog calculations for heating/cooling loads
2. Derivation of room weighting factors
3. In-depth observations of activities in the Hygrothermic Section of CSTB
4. Supplementary visits to other European laboratories for Environmental Engineering.

1. Introduction

During the visit of the first French team for the U.S./French Cooperative Program headed by Mr. Blachere to the Building Research Division of the National Bureau of Standards in November of 1969, it became apparent that the Environmental Engineering Section of NBS and the Hygrothermic Section of CSTB have each been engaged in several research programs such as heating/cooling load calculation, ventilation, wall heat conduction, and room air distributions. Both organizations have active programs for improving the calculations of the heating/cooling load of buildings. While the effort at NBS has been centered around the use of digital computers, French counterparts at CSTB have been employing an elaborate analog computer.

Mr. Borel, who represented the Hygrothermic Section of CSTB, and Mr. F. J. Powell of the Environmental Engineering Section of NBS, mutually agreed that comparative studies of heating/cooling load calculations for the same building performed by these two schemes should be of great interest for both organizations.

In addition, it was felt that a researcher from the Environmental Engineering Section would benefit very much by observing many of the French research activities related to the thermal performance of buildings. Subsequently, the author was selected to visit the CSTB to implement this phase of the U.S./French Cooperative Program. The program was carried out during the author's stay at CSTB in the period covering July 3 through July 28 according to the program shown in Appendix A. The comparison of the heating/cooling load calculation was completed and it was found that the results obtained by two different computing schemes agreed very well. Based upon this experience of comparing the computations by these two different types of computers, CSTB engineers prepared a new definition for extending the cooperative program of this kind, which is shown in Appendix B. Also included in this report are the summaries for the visits to several other European laboratories. These visits took place during and after the author's stay at CSTB. Other computed results of the previous studies made at the CSTB were utilized to derive weighting factors needed for the improvement of the NBS digital computer program, detail of which is shown in Appendix C. At the end of the visit a proposal stressing the need for a continued exchange of personnel and technical information was drafted. The proposal is attached to Appendix D.

2. Highlights of the CSTB Visit

On July 3, 1970, the author arrived in Paris and started to work at the research laboratories of CSTB (Centre Scientifique et Technique du Batiment), which is located in Champs-sur-Marne, approximately 20 miles east of Paris. He stayed there until July 28 and engaged in technical programs arranged by the CSTB personnel. The chronological detail of the program is attached in Appendix A.

During the author's stay, he worked with most of the engineers in the Hygrothemic Division (Mr. Croiset - Head), which is divided into two sections; Thermal Calculation Section (Mr. Anquez - Chief) and Design Concept Section (Mr. Borel - Chief).

Following are the highlights of his program:

1. The major purpose of the visit was to check the thermal load calculation procedures employed by CSTB engineers on their analog computer. A fictitious building of 11 rooms located at the latitude of 42 °W and longitude of 88 °N was chosen to compare the cooling load under a selected weather condition. The detail of building construction and occupancy and energy usage schedules are all shown in Figures 1 and 2 and Tables 1, 2 and 3. Only the cooling loads of 5 rooms on the second floor of the building were considered for the comparison. Figures 3 and 4 show the daily profiles of the cooling load of room 11 obtained by the U. S. Post Office digital computer

program and that calculated by the CSTB analog computer respectively, which shows very good agreement for the maximum thermal load.

Apparent discrepancy in the noon time dips of the thermal load of the two calculations is due to the fact that the internal heat load was treated as instantaneous in the CSTB calculations whereas the weighting factors to distribute it in a time domain were employed in the NBS calculations. Similar good agreements between the digital and analog computations were obtained for the other four rooms of the same sample building. In addition to the comparison of the thermal load, room temperature calculations for the NBS experimental building were also made by the NBS digital computer and CSTB analog computer. The agreement for the room temperature calculation was perfect. The CSTB analog computation is based upon a very exact radiative heat exchange process among the interior surfaces of the room whereas the U. S. Post Office computer program approximates this process by the weighting factor calculation procedure. The good agreement obtained between the two calculations is extremely important for NBS, who was evaluating the U. S. Post Office program under a specific research contract, with the U. S. Post Office Department.

2. Mr. Moyer has excellent background in analyzing heat conduction problems with the use of electrolytic tank and electric conduction paper. These devices were being used to study heat conduction from underground tunnels, exposed building floors (cold bridge effect), and underground heat distribution systems.

3. M. Gibert's activities on the ventilation of flats (apartment houses) and air flow characteristics of various air supply and exhaust systems are parallel to the research activities initiated in NBS by Mr. Myklebost and being continued by Professor Hill. Although the basic aims of these two investigations are not identical, it is possible to exchange experimental information. The goal of the NBS study is to obtain dynamic characteristics of the air leakage in conjunction with the outdoor wind characteristics and building construction (crack length and width), while M. Gibert's objective was to determine average air leakage rate from flats as functions of average outdoor weather condition and window openings. Mr. Gibert operates an experimental flat at Veyre, in the vicinity of CSTB research laboratory. An Agfa motorized camera was used to observe the window opening habits of the residents in the apartment house.

4. An optimization study on the heat recovery system being conducted by M. Galivier, one of the digital computer oriented engineers at CSTB, was very interesting. He proposes an unique heat exchanger for the ventilation and exhaust air streams which utilizes multiple layers of corrugated plastic sheets in a cross-flow fashion. The size of the heat exchanger was determined so that heat transfer effectiveness and fan horsepower requirement can be optimized.

5. Mr. Bertolo has developed a printed circuit long-wavelength radiometer to measure the radiative heat exchange of building surfaces with the sky. This apparatus is very useful for the evaluation of nighttime cooling of low cost houses. It was agreed that Mr. Bertolo would send one sample device to NBS for testing on a U. S. building. Mr. Bertolo has also obtained temperature transfer functions responding to a unit step change of thermal load. What is most needed for the heating/cooling load calculation procedure of the National Bureau of Standards computer program is the inverse of the temperature transfer function; the thermal load transfer function corresponding to a unit change of room temperature. This transfer function is called in the United States the weighting factors. Appendix C describes how the room temperature change weighting factors were derived from the data of Mr. Bertolo.

6. Prototype Design

CSTB, jointly with EDF (Electricité du France), now has design drawings for a prototype apartment, which has been conceived to embody the following objectives:

a. Use conventional construction practice

b. Electrically heated, but the total construction cost of the building is not to exceed by 20% the cost of non-electrically heated buildings

c. In order to justify the 20% additional expenditure, the thermal comfort throughout the year is to be better than the conventional design

d. A prototype building should be completed within two years

It is believed that all of these objectives can be met by a prototype design system which makes use of a resistance heater imbedded in the floor slab, a supplementary heater in the ventilation duct, exterior shading devices, 16 cm thick partition wall, and light weight panel exterior walls. A better than usual indoor thermal environment is assured by the design to allow a minimum temperature rise during summer, minimum cold draft during winter, avoidance of cold spots in windows (use of double glazed glass), small temperature stratification (2 °C) and effective means of distributing the air to the room. The prototype building design makes use of a heating control scheme such that the floor heating is done during the night and heat is to be stored for comfort during the day. Also, the exhaust heat recovery system is to be effectively employed.

The basic philosophy of the prototype is to design the building around the electric heating system in such a manner that the maximum thermal comfort and minimum energy requirements are insured simultaneously. Mr. Borel, an exponent of the prototype design is very hopeful that the United States would adopt the basic design concept to the experimental housing of the HUD Operation Breakthrough program.

7. Other Observations Include:

   a. Evaporative cooling of a school building

   b. Analog computer simulation of floor heated flats

   c. Analog computer study of room temperature response functions

8. Visits to Other Laboratories Arranged by CSTB

   a. EDF (Electricite du France) Research Laboratories in Ecuellis near Moret, a very pleasant one hour drive from Paris. The author met Messrs Michel and Lebault; both of them are on the staff of the

Application Department and are very active on the use of computers for environmental engineering related to electric heating and air conditioning. The application department, where environmental engineering studies are made, consists of 40 research personnel (10 engineers and 30 technicians) and operates on the annual budget of 5 million Francs (one million dollars). They have well equipped research facilities in the following areas:

luminaire

heat pumps

time constant for thermostats

induction unit cooling with electrical heaters

room air temperature distribution

heat pump heat recovery system (package)

office heat transfer affected by adjacent rooms

infrared surface temperature measurement

heat flow meter (TNO*) application
for the inner surface heat transfer coefficient study

computer calculation of heating/cooling load on the GE time shared system as well as on CDC 6600.

Energy calculation was done for 28 days per year, representing two days per month, one heating design day and three cooling design days.

b. CEDRIC (Centre d'etude de Documentation et de Decherche pou l'industrie du Chauffage du Conditsonment d'air et branches annex) in Liege Belgium was visited on July 22. Accompanying on the trip were Messrs Bertolo and Croiset of CSTB. We were greeted by Professor Barny, Messrs Lebran, Nusgens, Potier and Hannoy.

Mr. Lebran has just completed a PhD thesis based upon his work on air movement within a transparent prototype room of 4m x 4m x 2.7m. He has taken photographs of streak lines produced by metaldehyde particles following air motion created by various heating devices. His studies include the

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* A Dutch Government Research Laboratories.

recording of air velocity and temperature profile by thermister anemometers and resistance thermometers. He used 1 second exposure time with the f/5 camera opening and 3X film. The pictures were taken from different positions around the room to traverse the flow field. The partial photographs of the room sections were then pasted on 18" x 12" sheets in a mosaic fashion to review the overall flow pattern.

Mr. Lebran also has a 1/3 scale model of the prototype room filled with Freon to simulate the convection flow pattern.

In addition, the following research activities were observed:

Electrolytic analog studies on underground pipe heat transfer by Mr. Nusgens

Finite element heat conduction calculation by Mr. Portier

Thermal comfort and climate by Mr. Hannay

c. On July 23, the research laboratory of COSTIC (Comiti Scientifique et Technique de Lindustriedu Chaffage) was visited by Mr. Galivier, M. Anquez and the author. The COSTIC laboratory is operated by various organizations representing manufacturers and contractors and presently staffed with 60 personnel in which twelve are engineers.

We were met by Messrs Cadiergues (Director) and Thin, and shown their laboratory facilities which included:

- Wind tunnel (100 Km/hr max speed) for the wind around building model study
- Dehumidification coil testing
- Humidity calibration chamber
- Testing facilities for air conditioners, radiators, pressure relief valves, and heat exchangers

We found that they are a very progressive user of digital computers. They have IBM 1130 terminals connected to CDC 6600 for multitudes of HVAC type calculations. The most popular one of them is for the design and selection of radiators with the output being complete line drawings for the heating system made by a plotter. The service for this kind of computer calculation is 3.8 Francs per room. According to Mr. Cadiergues there have been 260,000 rooms designed with this program during 1969.

9. At the conclusion of the author's stay at CSTB, Messrs Croiset and Borel wanted to discuss the future cooperative program of CSTB and NBS. The proposals were drafted and approved by Mr. Blachere, Director of CSTB and are shown in Appendix D.

Table 1

LAYER NO.	L(I) ft	K(I) Btu per (hr)(ft)(F)	ρ(I) lb per cu ft	C(I) Btu per (lb)(F)	RES(I) (hr)(sq ft)(F) per Btu	DESCRIPTION OF LAYERS
1	0.042	0.830	55.00	0.400	0.00	1/2" Pitch and Slag
2	0.031	0.110	70.00	0.400	0.00	3/8" Felt
3	0.167	0.028	13.00	0.320	0.00	2" Insulation Board
4	0.333	1.000	140.00	0.200	0.00	4" Concrete
5	0.000	0.000	0.00	0.000	0.61	Air (ceiling side)

Table 2

LAYER NO.	L(I) ft	K(I) Btu per (hr)(ft)(F)	ρ(I) lb per cu ft	C(I) Btu per (lb)(F)	RES(I) (hr)(sq ft)(F) per Btu	DESCRIPTION OF LAYERS
1	.333	.770	125.00	.220	.00	4" Face Brick
2	.042	.420	116.00	.200	.00	1/2" Cement Mortar
3	.250	.430	120.00	.200	.00	8" Concrete Block
4	.250	.025	5.70	.300	.00	3" Insulation
5	.042	.270	90.00	.200	.00	1/2" Plaster Board
6	.000	.000	.00	.000	.68	Air (inside surface)

Table 3

Space (Room) No.	1	2	3	4	5	6	7	8	9	10	11
Window, Number					2	2				1	1
Orientation					E	E				E	E
Size (ft x ft)					8.75 x6	8.75 x6				23.5 x6	23.5 x6
Solar Factor (CSTB Definition) %					43	43				43	43
Floor area, ft^2	375	375	250	450	925	875	875	725	400	625	625
Room volume cu. ft	3750	3750	2500	4500	9250	8750	8750	7250	4000	6250	6250
Floor weight factor lb/ft^2					80						
Space temperature, °F					75						
Occupancy											
Maximum number	5	5	0	0	10	10	5	5	0	3	3
Activity level Btu/hr, person	600	600			600	600	600	600		400	400
Lighting											
Maximum KW / Maximum W/ft^2	1.5	1.5	4	1.8	3.1	3.5	3.5	2.9	1.6	2.5	2.5
Equipment											
Maximum KW			2								
Maximum W/ft^2	.75	.75		.7	1.85	1.75	1.75	1.45	0.8	1.25	1.25

Note: return air picks up a part of lighting heat

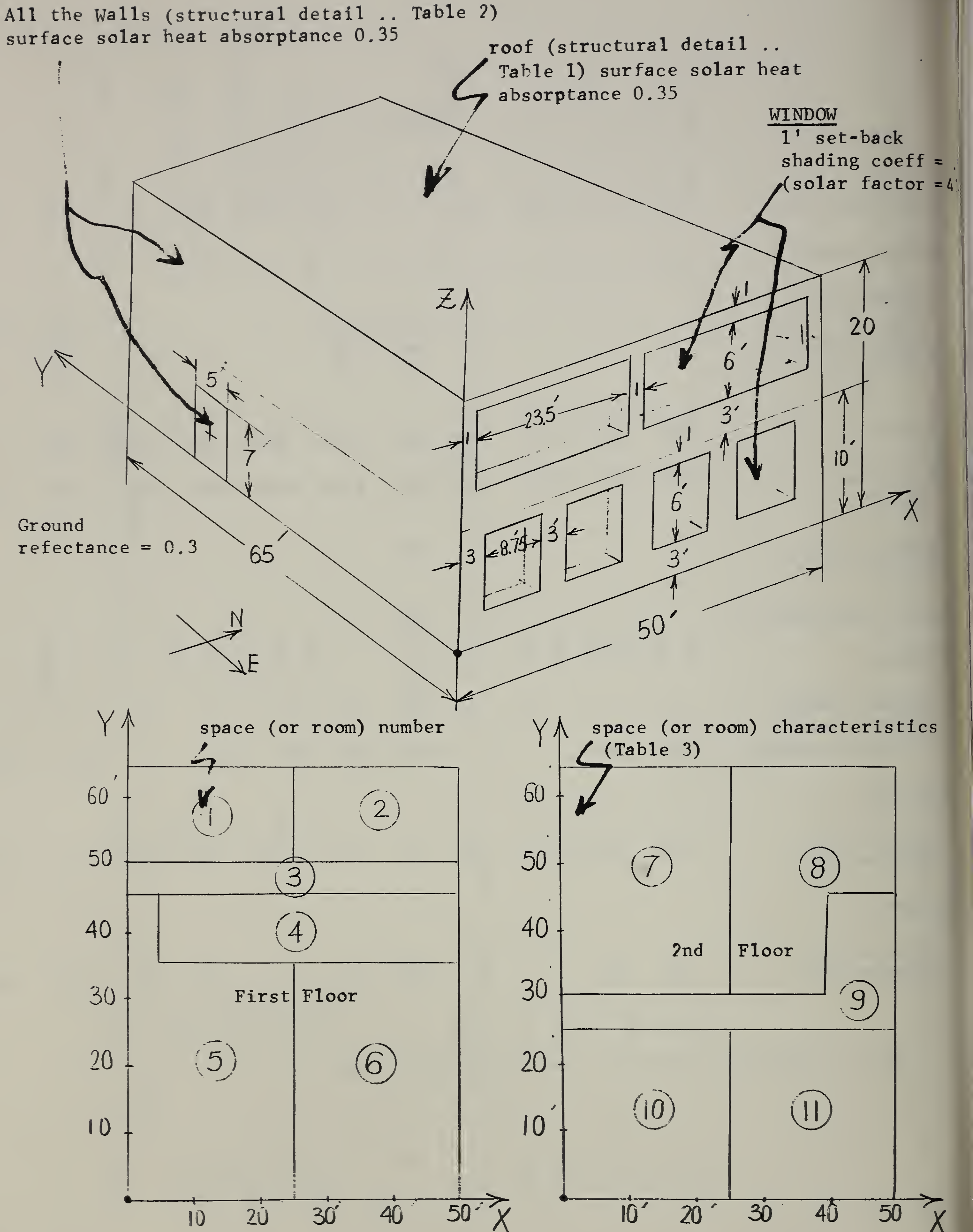

Figure 24 Isometric Line Sketch and Floor Plans of Example Building with Coordinate System, Main Dimensions and Space Numbers

all units in "foot"

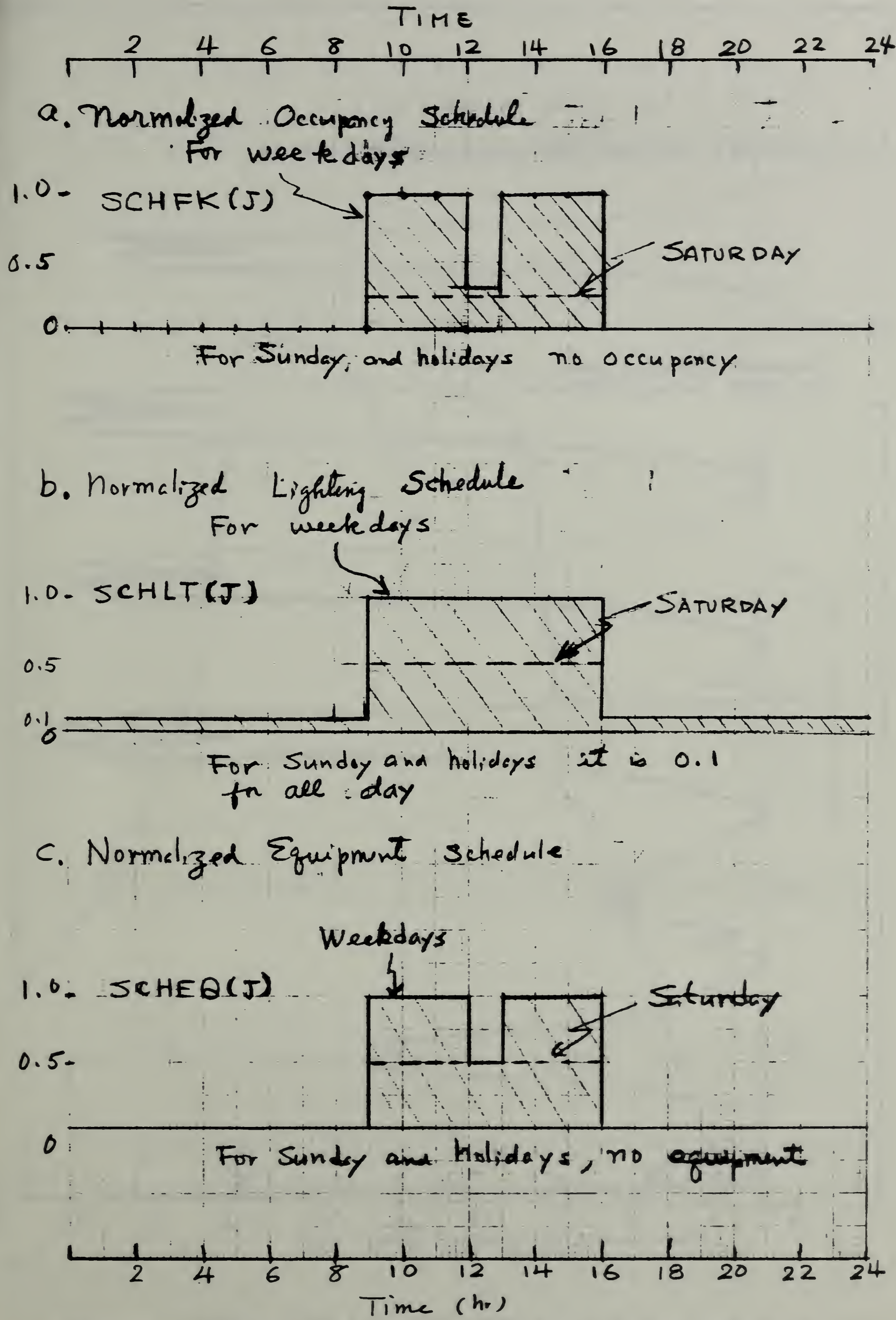

Figure 2 Schedules for Occupancy, Lighting and Internal Equipment

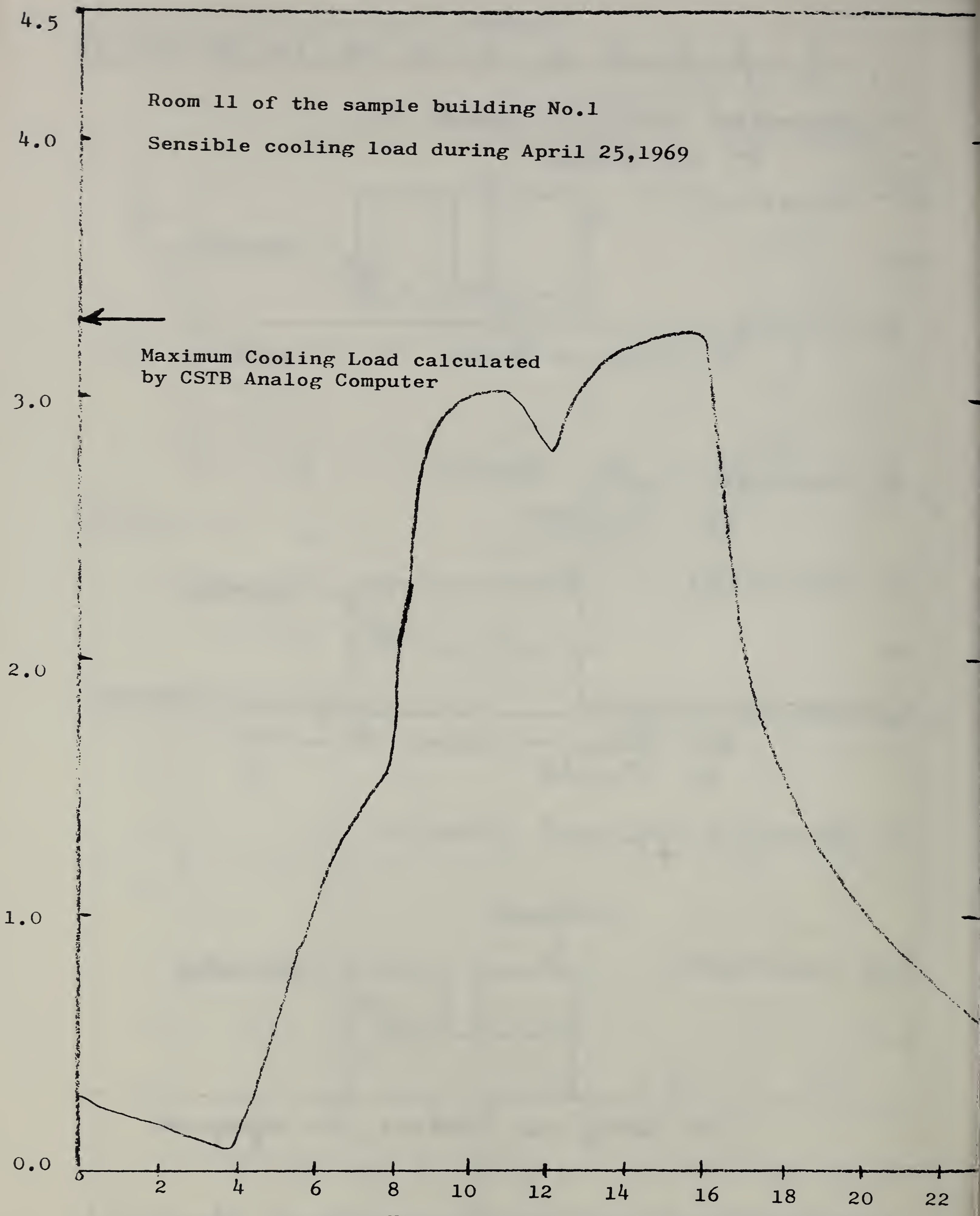

Figure 3 Sample Thermal Load Calculation by a Digital Computer

Trace of CSTB Analog Computation For Room 11

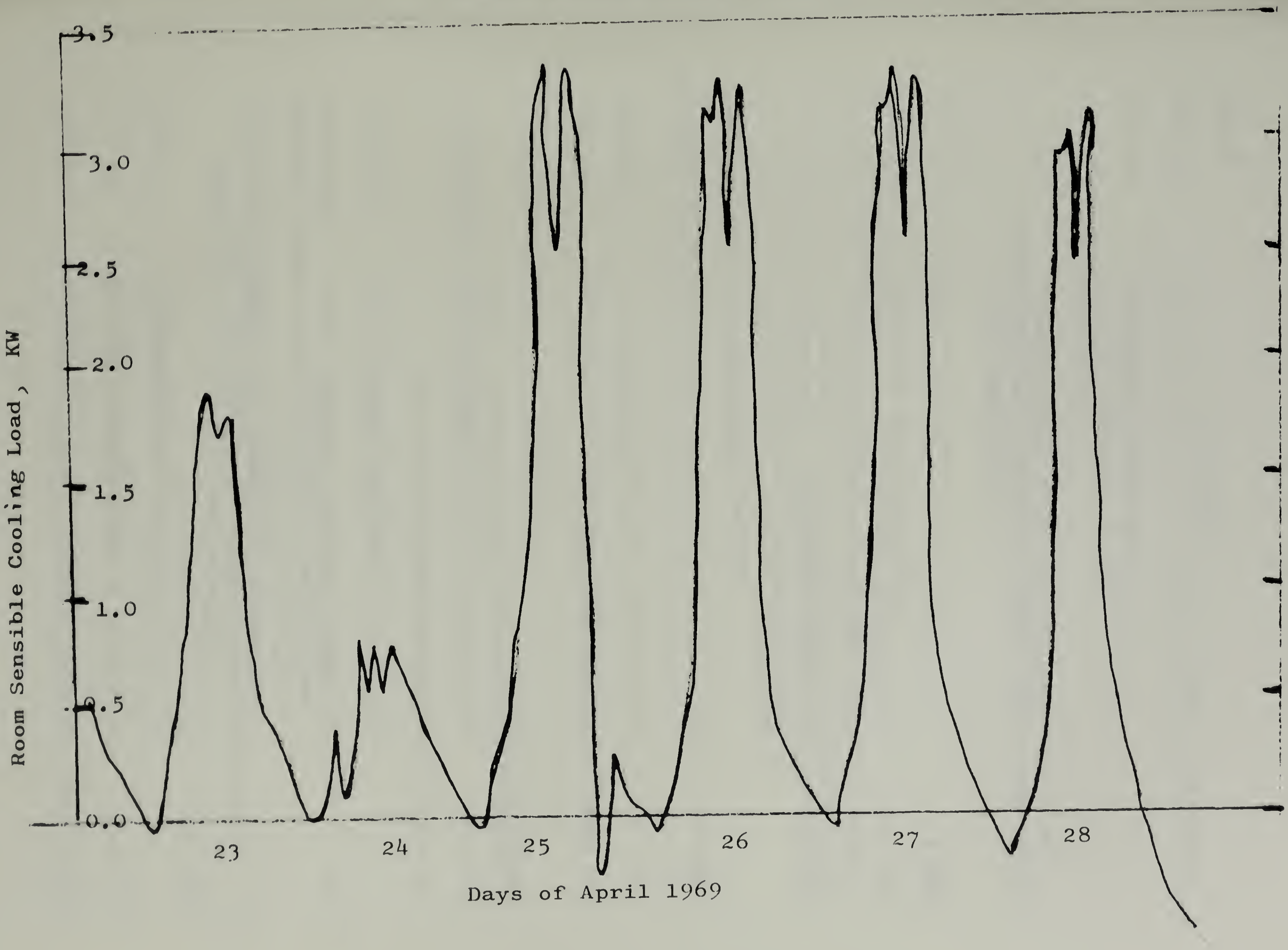

Figure 4 Sample Thermal Load Calculations by the CSTB Analog Computer

Appendix A

Dr. Kusuda's Stay at C.S.T.B.
(July 5 - July 29, 1970)

Stay Organizer: Service Hygrothermique et Ventilation (H.T.V.)

July 6

8:45 a.m.	Left hotel by car for C.S.T.B. Champs-sur-Marne laboratories
9:30 a.m.	Arrived at C.S.T.B.
	Discussion: Overview of H.T.V. works Program of the stay
1:00-3:00 p.m.	Lunch at C.S.T.B. with Mr. Blachere and H.T.V. engineers
3:00 p.m.	Visit of the C.S.T.B. laboratories
6:00 p.m.	Returned to hotel

July 7, 8, 9, 10, 15

8:30 a.m.	Left hotel for C.S.T.B. Champs-sur-Marne laboratories
9:15 a.m.	Arrived at C.S.T.B.
	Discussions and various works: - Papers sent by Dr. Kusuda - Possibilities of C.S.T.B. analog computer and works presently done with it - Determination of convection coefficients - Other C.S.T.B. - H.T.V. and NBS - BRD studies
12:45 p.m.	Lunch at C.S.T.B. (On July 9, lunch with Mr. Blachere)
2:00 p.m.	Carrying on of the discussions and works
6:00 or 6:30 p.m.	Returned to hotel

July 16

8:30 a.m.	Left hotel for C.S.T.B. Champs-sur-Marne laboratories
9:15 a.m.	Arrived at C.S.T.B.
	Discussion:
	- Whole design of prototype building (how to make the thermal equipment and the type of construction fit together)
12:45 p.m.	Lunch at C.S.T.B.
2:00 p.m.	Carrying on of the discussion
	- Prototype block of flats with electric heating, studied by C.S.T.B. and E.D.F. (French Electrical Authority). This study seems to correspond to the second phase of Breakthrough operation.
6:00 or 6:30 p.m.	Returned to hotel

July 17

8:45 a.m.	Left hotel for Courbevoie (West surburb of Paris)
9:15 a.m.	Arrived at Courbevoie
	Visit: British Petroleum Building (outside shading device)
	ESSO Building (inside shading device)
11:15 a.m.	Left Courbevoie for Paris
11:30 a.m.	Visit: Electrical heating by cables embedded in concrete floor (yard) - Champs-Elysees
12:30 p.m.	Visit: Bld Pereire Flat heated by electricity (double system: floor heating and convectors)
1:00 p.m.	Lunch in Paris
2:30 p.m.	Left Paris for Valenton
3:30 p.m.	Arrived in Valenton

Visit: Hot water floor heating and warm air with inlet near ceiling opposite to the facade

July 20, 21

9:00 a.m. — Left hotel for E.D.F. Renardieres laboratories, Moret-sur-Loing (Seine-et-Marne)

10:00 a.m. — Arrived at E.D.F.

Discussion and visit of laboratories of Electrical Applications Department (A.D.E.).
Contacts: Mr. Michel, Mr. Lebault

1:00 p.m. — Lunch at Moret-sur-Loing

3:00 or 4:00 p.m. — Returned to Paris

July 22

Trip to Liège (Belgium)

Visit of C.E.D.R.I.C. laboratory

Contact: Mr. Burnay, Director

July 23

9:00 a.m. — Left hotel for COSTIC Saint-Remy-les-Chevreuses laboratory

10:00 a.m. — Arrived at COSTIC

Discussion and visit of laboratory
Contact: Mr. Cadiergues, Director

July 24

8:00 a.m. — Left hotel for C.S.T.B. Champs-sur-Marne Laboratories

9:15 a.m. — Arrived at C.S.T.B.

Discussion about conclusion of the stay

10:15 a.m. — Left Champs-sur-Marne for C.S.T.B., Paris Building - 4, Avenue du Recteur Poincare

1:00 p.m.	Lunch with Mr. Blachere
2:30 p.m.	Discussion with Mr. Blachere
4:30 p.m.	Visit of the building (library ...)
5:00 p.m.	Returned to hotel

<u>July 27</u>

10:00 a.m.	Met with Mr. Greenberg, American Embassy
2:00 p.m.	Returned to C.S.T.B.
	Discussion on the future cooperative programs Conclusion of the exchange program

Appendix B

Utilization of the C.S.T.B.'s Analog Model to Improve the Digital Computer Program of NBS

prepared by

J. Anquez and Bertolo, CSTB

Final Object

It seems to be interesting to define from now the final object of the work in course.

1. The object of the digital computer program worked out by NBS is to give the survey offices and consulting engineers a tool for the calculation of the climatization plants power. This program might be improved owing to the computations made by the C.S.T.B. on his analog model and relating to the following points:

    a. better taking into account of the building inertia in the weighting factors calculation

    b. computations in the case where the inside temperature is not steady

    c. taking into account of some non-linearities convection coefficients on horizontal planes

    d. working out mathematical models representing controlling systems.

2. If NBS had also in view to work out a computation program for annual consumptions, C.S.T.B. might help NBS.

   a. on the first hand in the points detailed above

   b. on the other hand in utilization of climatic data, especially insolation and long-wave radiation.

Working Program

The conditioning loads calculation made with T. Kusuda's data has been made, for the C.S.T.B.'s part, with the whole of the loads in the air.

In T. Kusuda's calculation the loads are convective and radiative. Although the C.S.T.B. finds maximum load values very near of that calculated by T. Kusuda with however a difference in phase; this can be explained by the fact that the internal loads are steady over several hours; relating to the climatization loads this is nearly a steady state.

It would be interesting to make again such a calculation for a single room, varying the inertia and the dimensions (three cases must be adequate and for well defined radiative and convective characteristics of the internal loads.

With the same data it can be considered that the C.S.T.B. calculate weighting factors corresponding to a variation of the air temperature in the room.

Then T. Kusuda might use these last results in calculations that might be the following:

1. inside air temperature calculation in lack of climatization
2. inside air temperature and extracted heat amount (from which the consumption) for well defined operating conditions:
   a. plant power capacity lower than the maximum load
   b. plant operation stopping during some periods (week-ends)
   c. systematic limitation of the available power during the maximum load periods, and for given characteristics of the equipment and of its control (particularly proportional control).

For his part C.S.T.B. might do the same calculations by means of the analog method so that the results may be compared.

The calculation of the weighting factors directly usable into a digital computation program can be considered after the utilization limit of a given weighting factor would have been determined, that is to say the number of cases to be calculated (the C.S.T.B. study into the building classification owing to their unit step response might be used as a basis).

Moreover the C.S.T.B. is in possession of hourly real climatic data over two years (grouped on punched cards) containing particularly the total and diffuse insolations on an horizontal plane. Perhaps might it be possible to use them for the calculations.

Appendix C

Weighting Factors for the Room Temperature Change

Since modern buildings have a high degree of dependency upon the thermal loads which vary during the course of a day, such as heat generated by lighting, equipment, and occupancy and heat gain by solar radiation, it has been a trend to conduct the energy estimate calculation on the hourly basis.

In the United States it has been customary to perform the hourly thermal load calculation on the basis of constant room temperature. Actual thermal load imposed on the equipment (sometimes it is called the heat extraction), however, has been observed to be much less than thermal load computed under a realistic condition when the room temperature is allowed to change as function of indoor and outdoor operating conditions.

A simple yet dramatic example of this point is illustrated in Figure 1, which depicts the indoor temperature of the experimental building of the National Bureau of Standards and the controlled outdoor temperature imposed upon the building. The experimental building was not heated or cooled during the test.

Although the outdoor temperature cycle was designed to produce a large diurnal amplitude, the indoor temperature of this building stayed relatively constant to within $\pm$ 2 °F of the diurnal average temperature.

If the thermal load calculation was made on the basis of constant room temperature, this building would have required heating during a part of the day and cooling during another part of the day. But if ± 2 °F change from the average air temperature is tolerated, this building would have needed no energy for maintaining the required indoor environment.

A point to be emphasized is the fact that if the thermal load calculation is to be made for the purpose of estimating hourly energy requirement, it must take into account the effect of room air temperature change.

Exact calculation technique to account for the room air temperature change upon the thermal load is, however, extremely complex and it requires solution of simultaneous equations describing the heat exchange among various surfaces and that between the air and the surfaces*. If each complex calculation is to be repeated for every hour, particularly for a building with a multitude of rooms, the computation time will be excessive. In order to decrease the computational effort, the ASHRAE Task Group on Energy Requirements suggests the use of weighting factors which may be defined as follows:

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* G. P. Mitalas and D. G. Stephenson, Room Thermal Response Factors, ASHRAE Transactions, 1967, Vol. 73.

$$Q_t = \sum_{j=o}^{\infty} W_j \, (T - T_o)_{t-j} \tag{1}$$

where Q_t = effect on heating/cooling load due to the room air temperature change

W_j = weighting factor for the room air temperature change

$T_t - T_o$ = room air temperature change from the set point

The value of W_j can be determined, if enough data for Q_t and θ_t are available, by a regression technique, one of which could be the Wiener filtering technique**.

The data to be used for solving for W_j from a regression procedure on equation (1), however, must be obtained by exact solution of the simultaneous equation describing the air-surface heat exchange, which was mentioned earlier. Such exact calculations have been obtained at the Centre Scientifique et Technique du Batiment (CSTB) of France for a typical room with various construction characteristics (Figure 2 shows the room dimension). The exact solutions were, however, obtained in the form of room temperature responsive to a step change of thermal load, which is schematically shown in Figure 3. When the data of CSTB were rearranged and plotted in semi-logarithmic sheet against time steps, they form a linear relationship except for the first value, such as shown in Figures 3, 4, 5, and 6.

** E. A. Robinson, Multi-channel Time Series Analysis, Holden-Day, 1967.

Using this semi-logarithmic relationship, the temperature response function for a step increase of the load may be expressed as follows:

$$
\begin{aligned}
\text{at}\quad & t = 0,\ \theta_o = A \\
& t = \Delta,\ \theta_1 = Br \\
& t = 2\Delta,\ \theta_2 = Br^2 \\
& t = \overline{j\Delta},\ \overline{\theta_j} = Br^j
\end{aligned}
\qquad (2)
$$

where $\theta_j = \dfrac{T\infty - T_j}{T\infty - T_o}$

T_o = a set point temperature of the room

$T\infty$ = final temperature of the room when a step of L = 1 is applied

$r = e^{-\beta\Delta}$

β = slope of the semi-log plot of the temperature response

Δ = time increment

B = intercept of the semi-logarithmic plot at t = o.

Table I shows the value of A, B and r determined from the CSTB data.

By applying the equation (1) to the CSTB data, the following relationships are evident

$$
\begin{aligned}
1 &= W'_o\ \theta_o \\
1 &= W_o'\ \theta_1 + W_1'\ \theta_o \qquad (3)\\
1 &= W_o'\ \theta_2 + W_1'\ \theta_1 + W_2'\ \theta_o \\
1 &= \sum_{j=o}^{\infty} W_j'\ \theta_{t-j} \quad \text{when } W_j' = W_j\ (T\infty - T_o)
\end{aligned}
$$

This equation may be solved recursively to obtain the values of W_j as follows:

$$W_o' = 1/A$$

$$W_1' = \frac{1}{A} [1 - W_o' \cdot Br] \tag{4}$$

$$W_2' = \frac{1}{A} [1 - W_1' \cdot Br - W_o' \cdot Br^2]$$

It turns out, however, that the value of W_j decays very slowly as the index of j increases so that a large number of weighting factor terms are required to calculate Q_t by equation (1). The calculation can be simplified very much by applying a z-transformation technique*.

The z-transformation presentation of equation (1) is

$$\sum_{j=o}^{\infty} Q_j Z^j = (\sum_{j=o}^{\infty} W'_j Z^j) (\sum_{j=o}^{\infty} \theta_j Z^j) \tag{5}$$

By noting the fact that a polynomial of infinite length can be represented by the ratio of two finite length polynomials, one can write

$$\sum^{\infty} W_j' Z^j = \frac{\sum_{j=o}^{Na} a_j Z^j}{\sum_{j=o}^{Nb} b_j Z^j}$$

---

* R. J. Schwarz and B. Friedland, Linear Systems, McGraw Hill Book Co., 1965, pp. 234-267.

Simplest polynomials to satisfy the CSTB data, which can be represented by three basic parameters, A, B, and r, are found to be (after several trials)

$$\sum_{j=0}^{\infty} W_j' Z^j = \frac{a_o + a_1 Z}{1 + b_1 Z + b_2 Z^2}$$

where $a_o = 1/A$

$a_1 = -\frac{r}{A}$

$b_o = 1$

$b_1 = -(1 + r - \frac{B}{A} r)$

$b_2 = r(1 - \frac{B}{A})$

In other words, the weighting factors W_j for $j = 0, 1, \ldots \infty$ can be generated by these five basic constants by a polynomial division. The use of W_j' is, however, unnecessary because the hourly load can now be obtained by a simple finite expression such that

$$Q_1 = (a_o \theta_t + a_1 \theta_{t-1} - b_1 Q_{t-1} - b_2 Q_{t-2})/b_o$$

This expression requires temperature history of one time step and the load history of one and two time steps.

Tables II through 12 show values of a_o, a_1, b_o, b_1 and b_2 and Q_t calculated by equation (8) for $\theta_o = 1$ and $\theta_t = 0$ for at $t > o$.

Also shown in the same table is the value of 0_t calculated by

$$\theta_t = \frac{1}{a_o} [b_o Q_t + b_1 Q_{t-1} + b_2 Q_{t-2} - a_1 \theta_{t-1}] \qquad (9)$$

which is the reciprocal relation of (8) for $Q_t = 1$ for all $t \geq o$.

Table II shows that under a step increase of temperature, the value of Q_t rapidly converges to a final stationary value, which is

$$Q\infty = \frac{1 - r}{A (1 - r) + Br} \qquad (10)$$

while the value of θ_t slowly decreases to zero under the step increase of Q.

Room Type	U	A	B	r
a	1.03	0.9	0.84	.841
b	"	0.9	0.63	.782
c	"	0.92	0.90	.846
d	"	0.92	0.84	.739
a	2.40	0.86	0.85	.892
b	"	0.86	0.78	.790
c	"	0.84	0.73	.881
d	"	0.84	0.50	.849
a	5.88	0.75	0.74	.559
b	"	0.75	0.71	.345
c	"	0.71	0.51	.646
d	"	0.71	0.30	.589

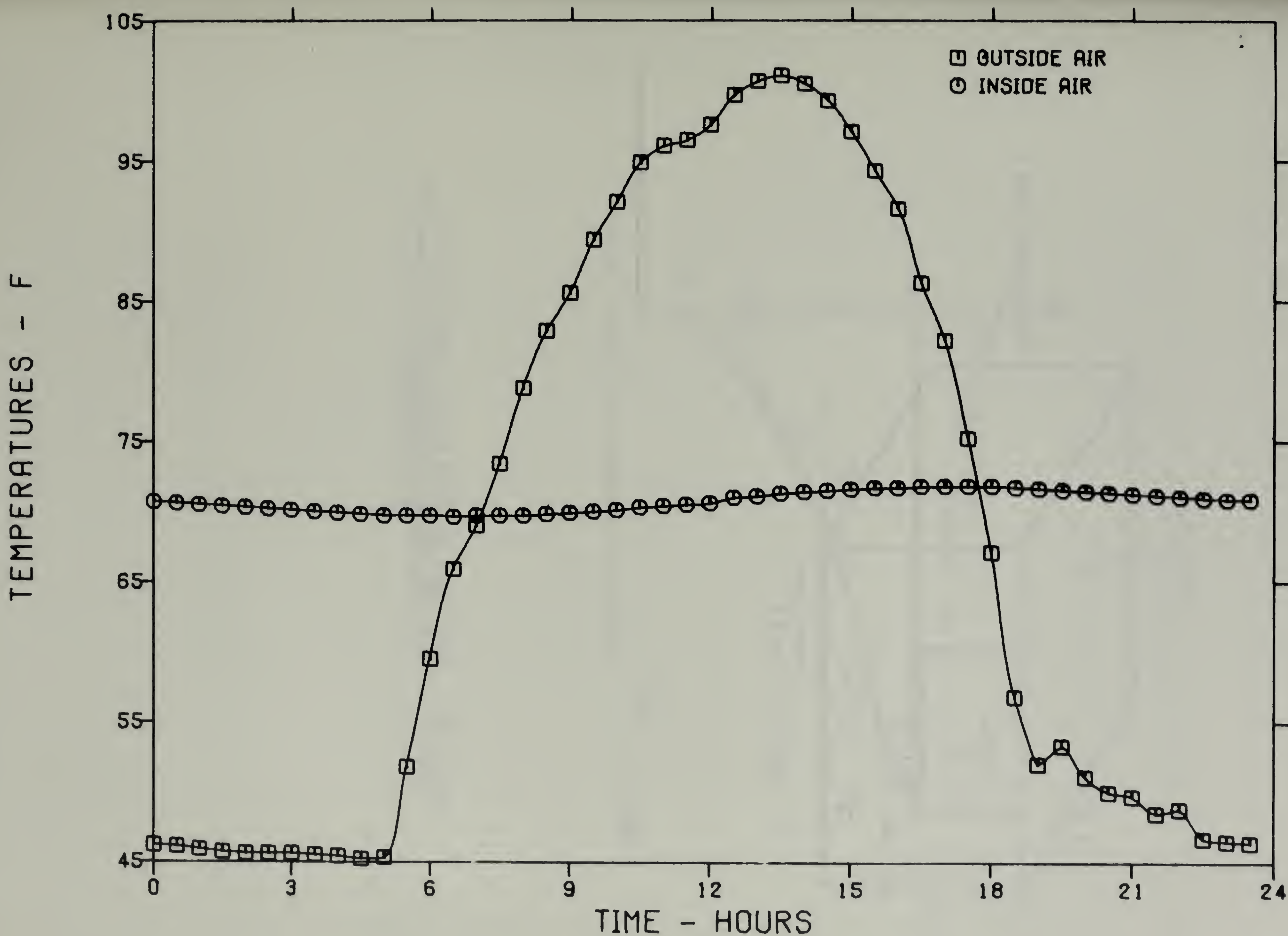
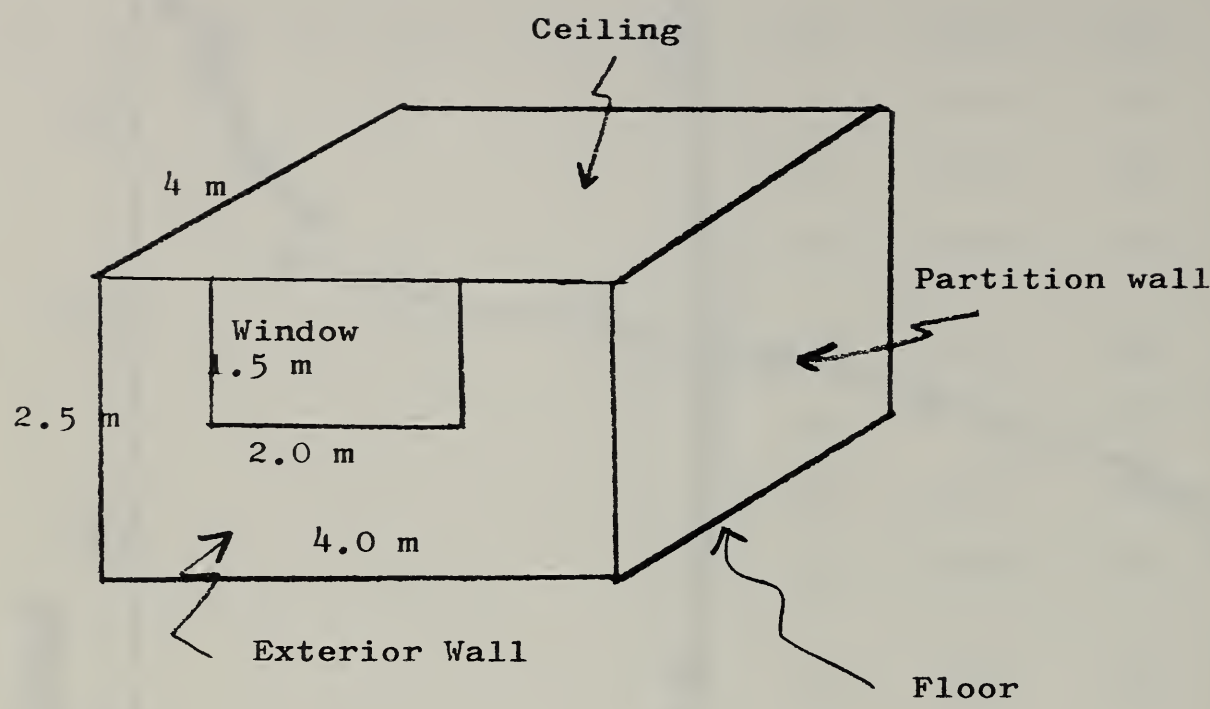


Figure 1A In- and Outdoor Temperature Profiles of a Non-Air-Conditioned Building



Room Air Change per Hour N= 1.0

Figure 2A Room Used by CSTB Analog Computers for the Calculation of Transfer Functions

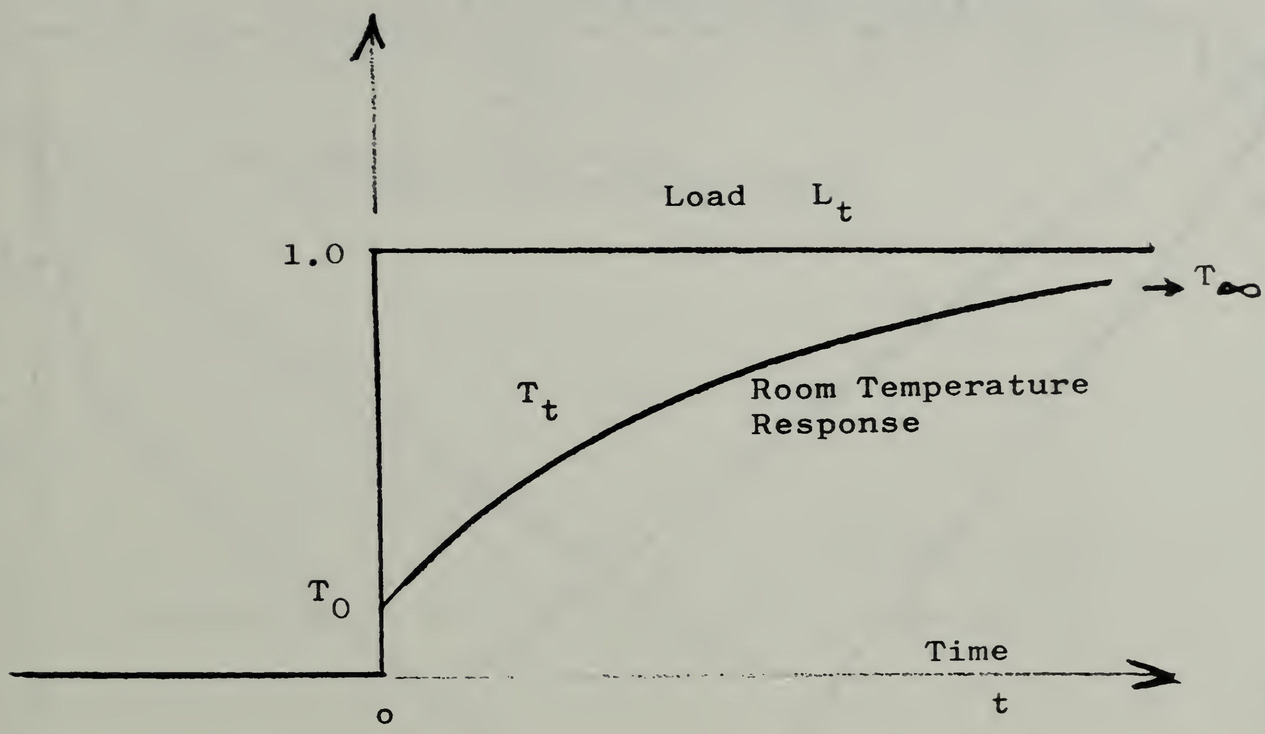


Figure 3A Temperature Response for a Step Increase of Thermal Load

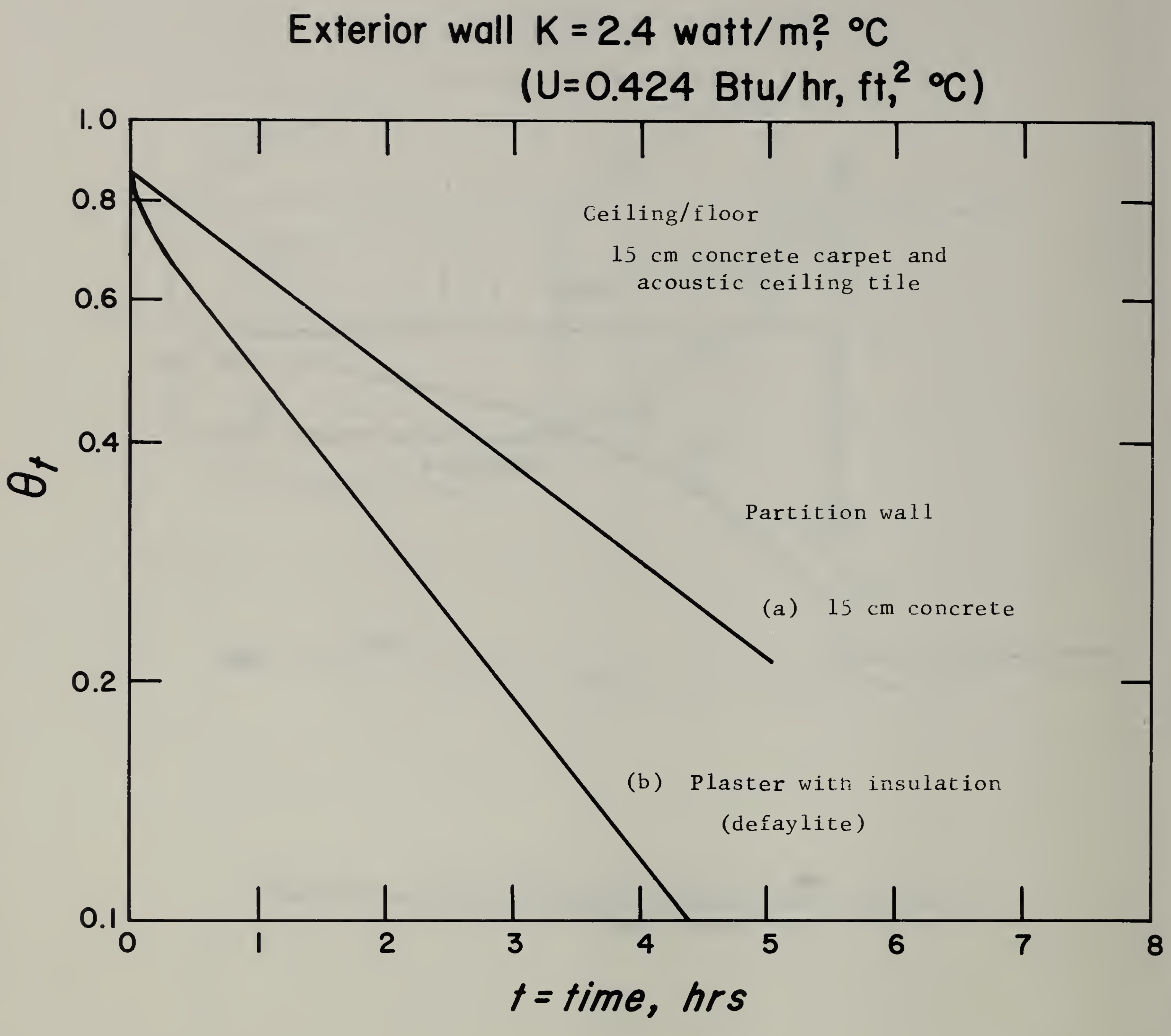


Figure 4A Room Temperature Response Function for the Step Increase of Thermal Load Input

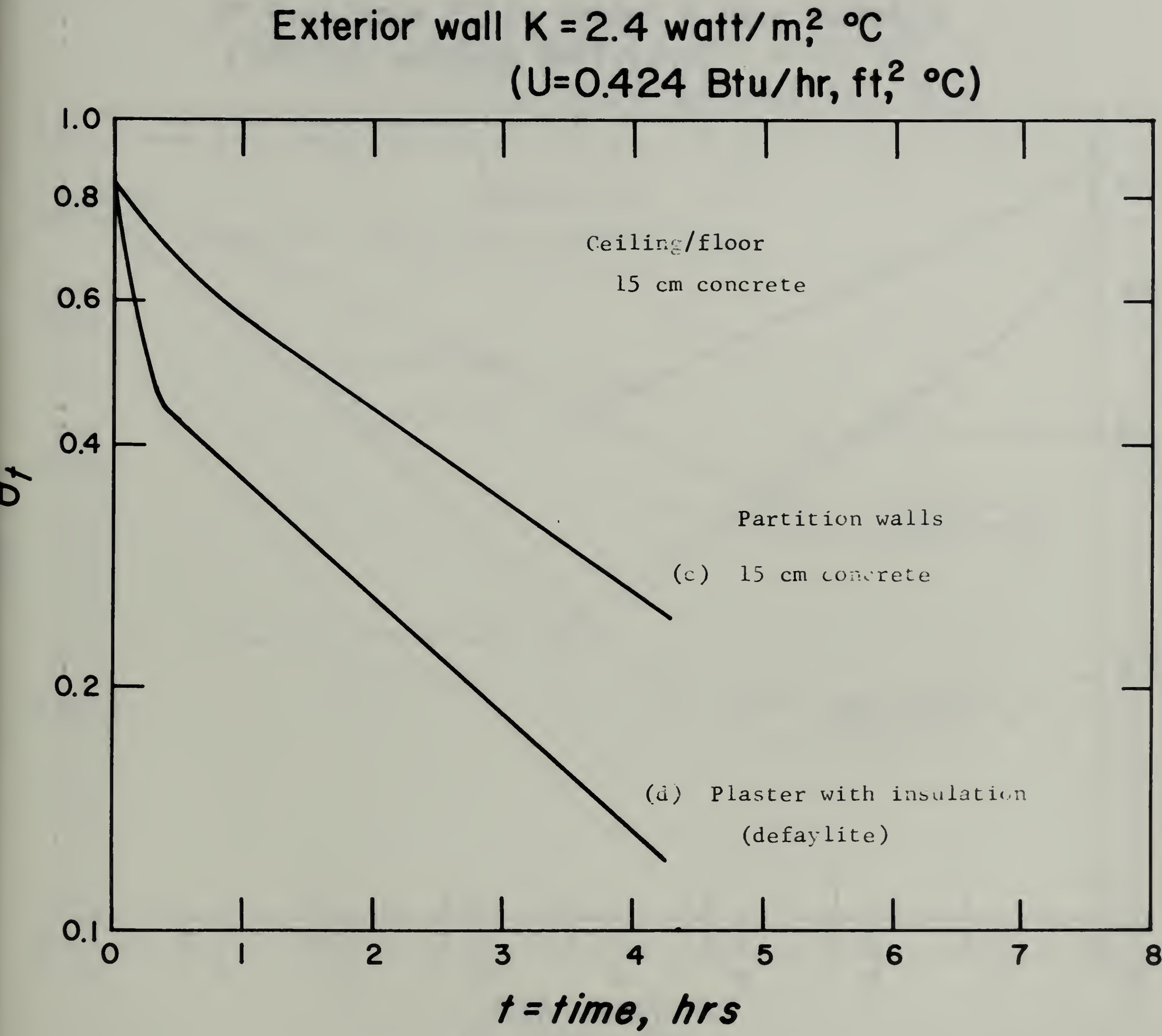


Figure 5A Room Temperature Response Function for the Step Increase of Thermal Load Input

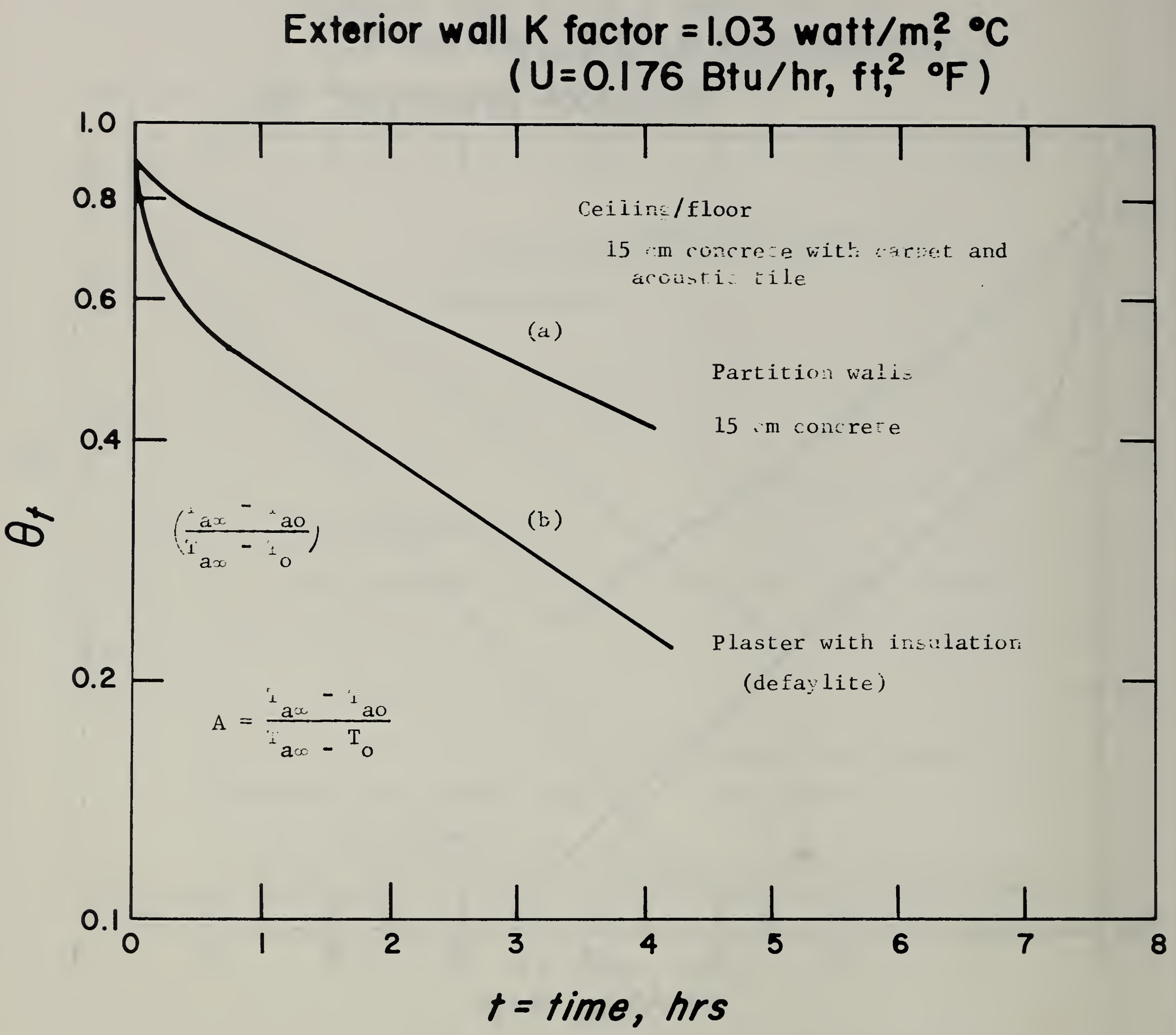


Figure 6A Room Temperature Response Function for the Step Increase of Thermal Load Input

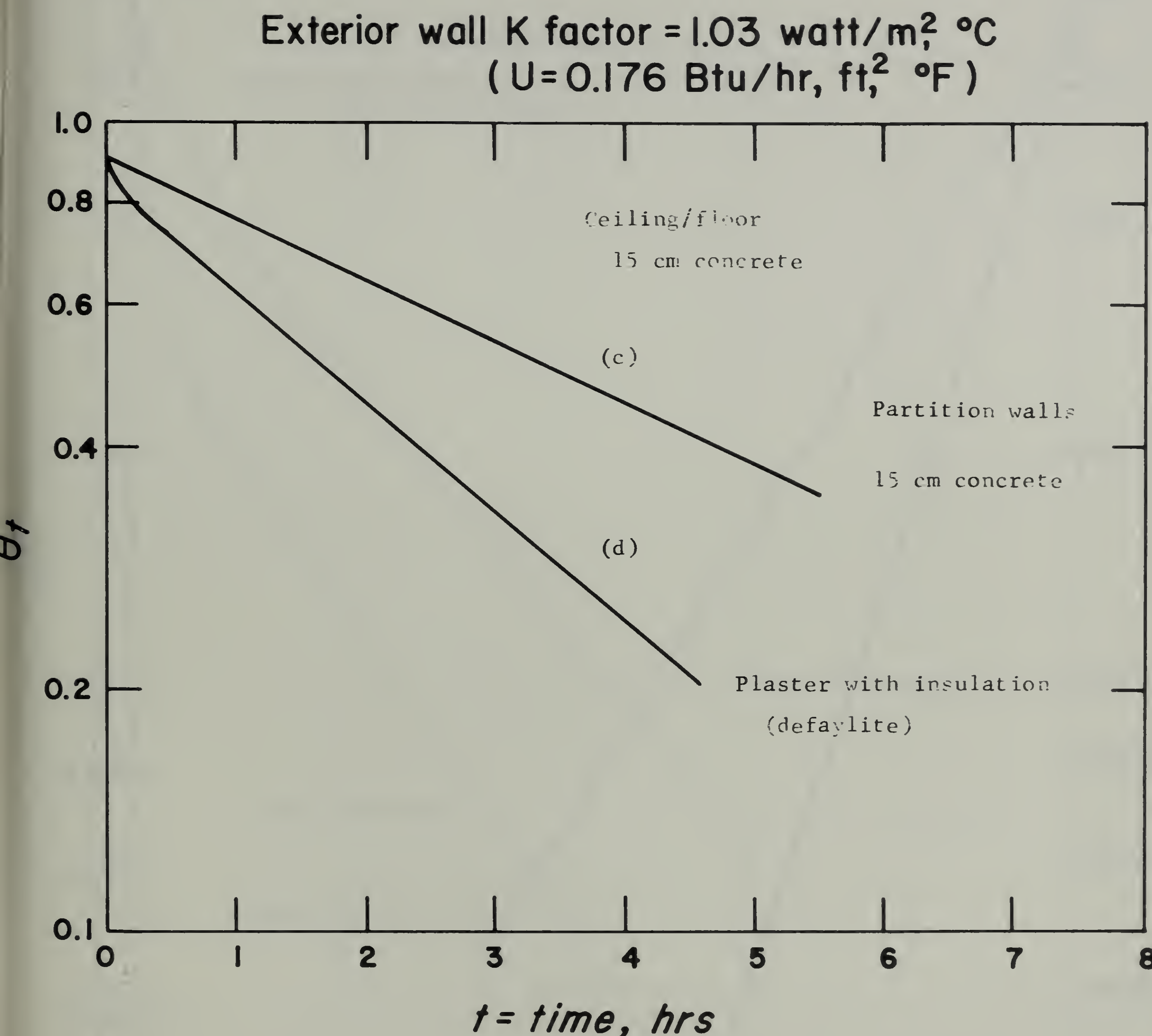


Figure 7A Room Temperature Response Function for the Step Increase of Thermal Load Input

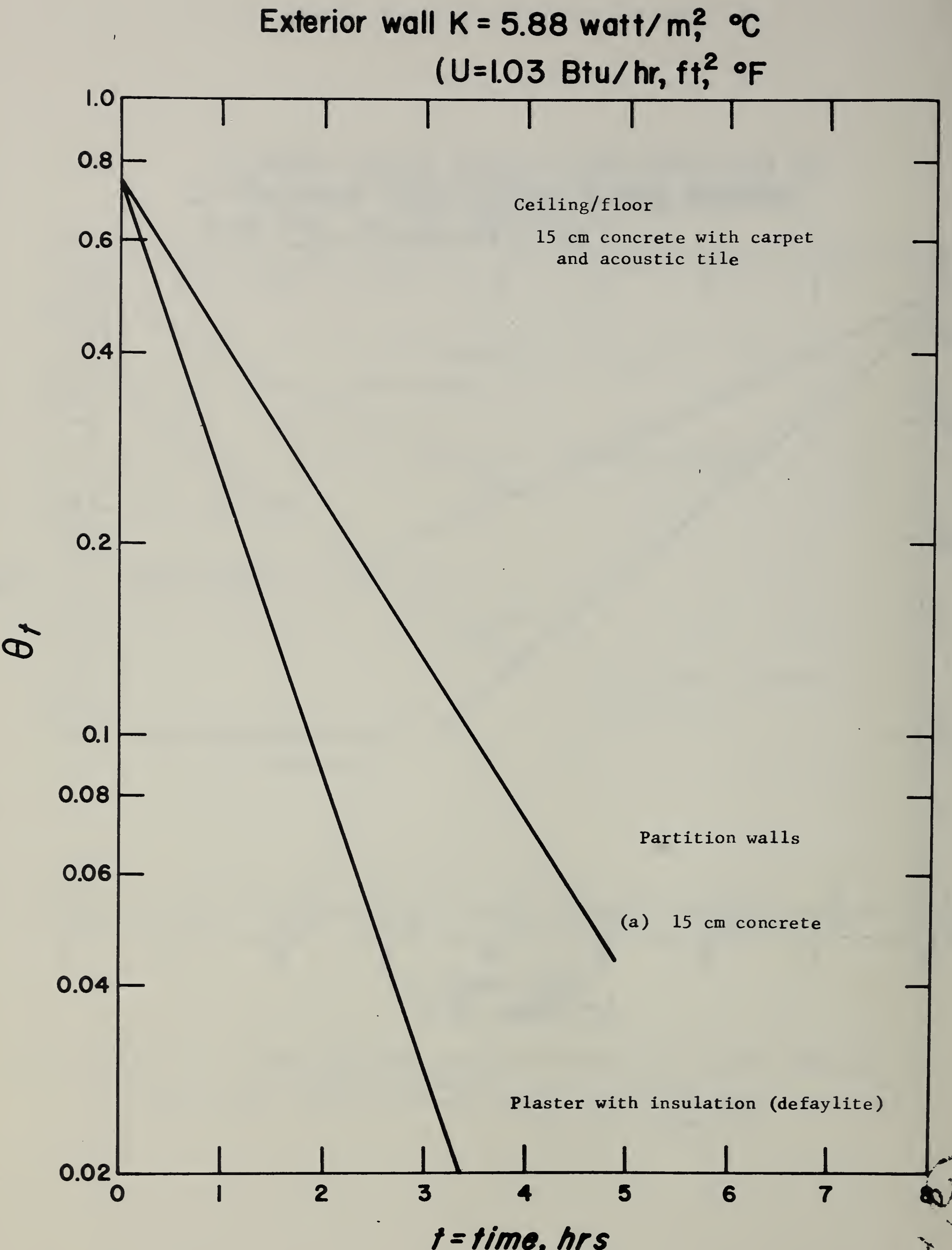


Figure 8A Room Temperature Response Function for the Step Increase of Thermal Load Input

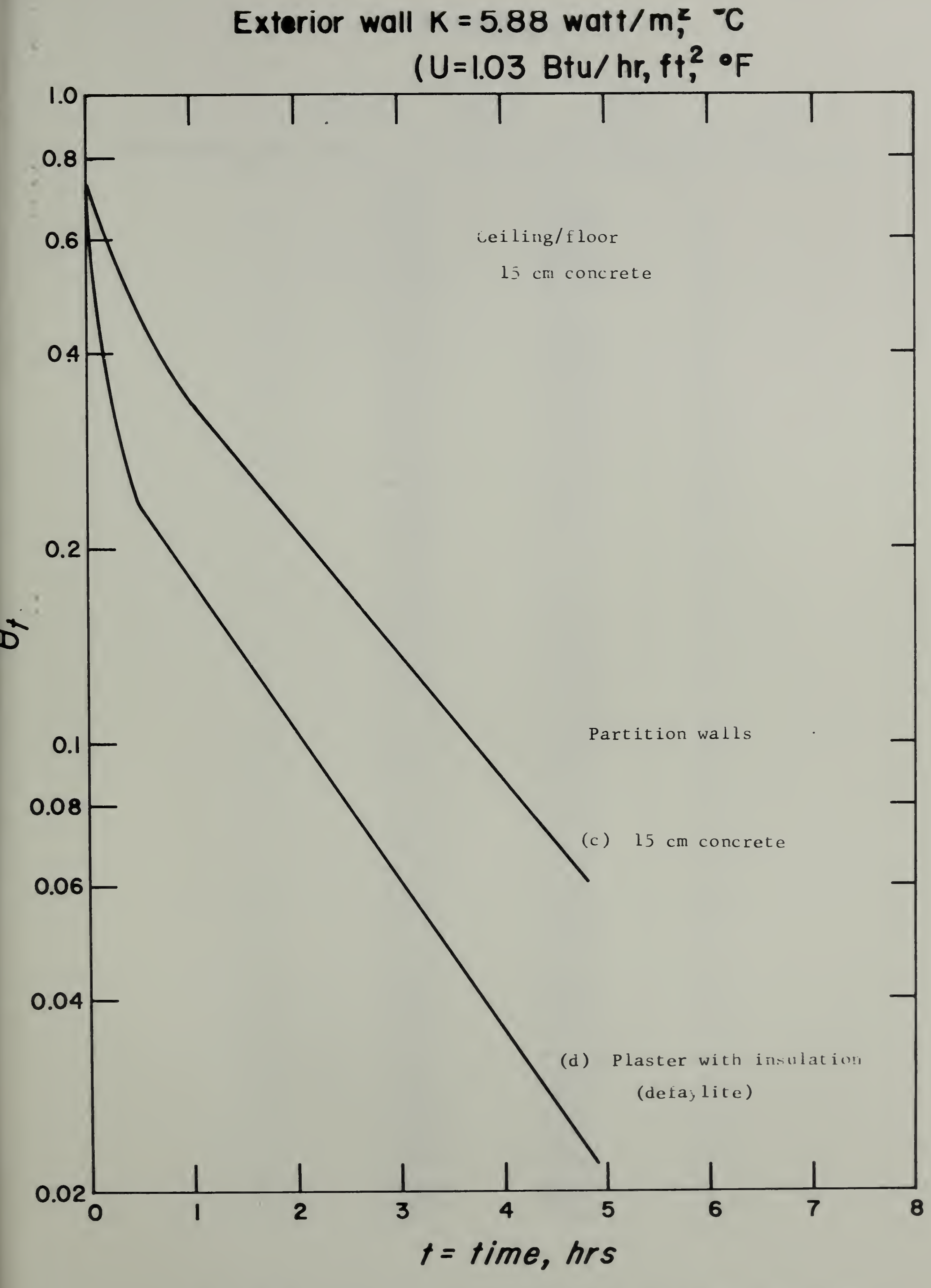


Figure 9A Room Temperature Response Function for the Step Increase of Thermal Load Input

Table II - 1

A= .900 B= .840 K= 1.030

A0= .9000 A1=-.9505 A2= .0505 B0=1.0000 B1=-.8409

J	S(J)	T(J)
1.	1.1111	.9000
2.	.2391	.7064
3.	.1902	.5940
4.	.1874	.4995
5.	.1873	.4200
6.	.1873	.3532
7.	.1873	.2970
8.	.1873	.2497
9.	.1873	.2100
10.	.1873	.1766
11.	.1873	.1485
12.	.1873	.1249
13.	.1873	.1050
14.	.1873	.0883
15.	.1873	.0742
16.	.1873	.0624
17.	.1873	.0525
18.	.1873	.0441
19.	.1873	.0371
20.	.1873	.0312
21.	.1873	.0263
22.	.1873	.0221
23.	.1873	.0186
24.	.1873	.0156
25.	.1873	.0131
26.	.1873	.0110
27.	.1873	.0093
28.	.1873	.0078
29.	.1873	.0066
30.	.1873	.0055
31.	.1873	.0046
32.	.1873	.0039
33.	.1873	.0033
34.	.1873	.0028
35.	.1873	.0023
36.	.1873	.0020
37.	.1873	.0016
38.	.1873	.0014
39.	.1873	.0012
40.	.1873	.0010
41.	.1873	.0008
42.	.1873	.0007
43.	.1873	.0006
44.	.1873	.0005
45.	.1873	.0004
46.	.1873	.0003
47.	.1873	.0003
48.	.1873	.0002

Table II - 2

A= .900 F= .430 K= 1.030

A0= .9070 A1=******* A2= .2110 B0=1.0000 B1=-.7815

J	Q(J)	T(J)
1.	1.1111	.9000
2.	.5033	.4923
3.	.3608	.3648
4.	.3278	.3007
5.	.3195	.2350
6.	.3177	.1837
7.	.3173	.1435
8.	.3172	.1122
9.	.3171	.0877
10.	.3171	.0685
11.	.3171	.0535
12.	.3171	.0418
13.	.3171	.0327
14.	.3171	.0256
15.	.3171	.0200
16.	.3171	.0156
17.	.3171	.0122
18.	.3171	.0095
19.	.3171	.0074
20.	.3171	.0058
21.	.3171	.0045
22.	.3171	.0036
23.	.3171	.0028
24.	.3171	.0022
25.	.3171	.0017
26.	.3171	.0013
27.	.3171	.0010
28.	.3171	.0008
29.	.3171	.0006
30.	.3171	.0005
31.	.3171	.0004
32.	.3171	.0003
33.	.3171	.0002
34.	.3171	.0002
35.	.3171	.0001
36.	.3171	.0001
37.	.3171	.0001
38.	.3171	.0001
39.	.3171	.0001
40.	.3171	.0000
41.	.3171	.0000
42.	.3171	.0000
43.	.3171	.0000
44.	.3171	.0000
45.	.3171	.0000
46.	.3171	.0000
47.	.3171	.0000
48.	.3171	.0000

Table II - 3

A= .920B= .900K= 1.030

A0= .9200 A1=-.9369 A2= .0169 B0=1.0000 B1=-.8455

J	D(J)	T(J)
1.	1.0870	.9200
2.	.1872	.7610
3.	.1714	.6434
4.	.1711	.5440
5.	.1710	.4600
6.	.1710	.3889
7.	.1710	.3289
8.	.1710	.2781
9.	.1710	.2351
10.	.1710	.1988
11.	.1710	.1681
12.	.1710	.1421
13.	.1710	.1202
14.	.1710	.1016
15.	.1710	.0859
16.	.1710	.0726
17.	.1710	.0614
18.	.1710	.0519
19.	.1710	.0439
20.	.1710	.0371
21.	.1710	.0314
22.	.1710	.0265
23.	.1710	.0224
24.	.1710	.0190
25.	.1710	.0160
26.	.1710	.0136
27.	.1710	.0115
28.	.1710	.0097
29.	.1710	.0082
30.	.1710	.0069
31.	.1710	.0059
32.	.1710	.0050
33.	.1710	.0042
34.	.1710	.0035
35.	.1710	.0030
36.	.1710	.0025
37.	.1710	.0021
38.	.1710	.0018
39.	.1710	.0015
40.	.1710	.0013
41.	.1710	.0011
42.	.1710	.0009
43.	.1710	.0008
44.	.1710	.0007
45.	.1710	.0006
46.	.1710	.0005
47.	.1710	.0004
48.	.1710	.0003

Table II - 4

A= .920 C= .840 K= 1.030

A0= .9200 A1=-.9791 A2= .0521 B0=1.0000 B1=-.7386

J	Q(J)	T(J)
1.	1.0870	.9200
2.	.3539	.6204
3.	.3069	.4583
4.	.3038	.3385
5.	.3036	.2500
6.	.3036	.1847
7.	.3036	.1364
8.	.3036	.1007
9.	.3036	.0744
10.	.3036	.0550
11.	.3036	.0406
12.	.3036	.0300
13.	.3036	.0221
14.	.3036	.0164
15.	.3036	.0121
16.	.3036	.0089
17.	.3036	.0066
18.	.3036	.0049
19.	.3036	.0036
20.	.3036	.0027
21.	.3036	.0020
22.	.3036	.0014
23.	.3036	.0011
24.	.3036	.0008
25.	.3036	.0006
26.	.3036	.0004
27.	.3036	.0003
28.	.3036	.0002
29.	.3036	.0002
30.	.3036	.0001
31.	.3036	.0001
32.	.3036	.0001
33.	.3036	.0001
34.	.3036	.0000
35.	.3036	.0000
36.	.3036	.0000
37.	.3036	.0000
38.	.3036	.0000
39.	.3036	.0000
40.	.3036	.0000
41.	.3036	.0000
42.	.3036	.0000
43.	.3036	.0000
44.	.3036	.0000
45.	.3036	.0000
46.	.3036	.0000
47.	.3036	.0000
48.	.3036	.0000

Table II - 5

A= .860 B= .850 K= 2.400

A0= .8600 A1=-.3687 A2= .0087 B0=1.0000 B1=-.8723

J	D(J)	T(J)
1.	1.1628	.8600
2.	.1603	.7415
3.	.1501	.6468
4.	.1500	.5642
5.	.1500	.4922
6.	.1500	.4293
7.	.1500	.3745
8.	.1500	.3267
9.	.1500	.2850
10.	.1500	.2486
11.	.1500	.2169
12.	.1500	.1892
13.	.1500	.1650
14.	.1500	.1440
15.	.1500	.1256
16.	.1500	.1095
17.	.1500	.0956
18.	.1500	.0834
19.	.1500	.0727
20.	.1500	.0634
21.	.1500	.0553
22.	.1500	.0483
23.	.1500	.0421
24.	.1500	.0367
25.	.1500	.0320
26.	.1500	.0279
27.	.1500	.0244
28.	.1500	.0213
29.	.1500	.0186
30.	.1500	.0162
31.	.1500	.0141
32.	.1500	.0123
33.	.1500	.0107
34.	.1500	.0094
35.	.1500	.0082
36.	.1500	.0071
37.	.1500	.0062
38.	.1500	.0054
39.	.1500	.0047
40.	.1500	.0041
41.	.1500	.0036
42.	.1500	.0031
43.	.1500	.0027
44.	.1500	.0024
45.	.1500	.0021
46.	.1500	.0018
47.	.1500	.0016
48.	.1500	.0014

Table II - 6

A= .860B= .780K= 2.400

A0= .8600 A1=-.9232 A2= .0632 B0=1.0000 B1=-.7897

J	Q(J)	T(J)
1.	1.1628	.8600
2.	.3299	.6160
3.	.2687	.4865
4.	.2643	.3842
5.	.2639	.3034
6.	.2639	.2396
7.	.2639	.1892
8.	.2639	.1494
9.	.2639	.1180
10.	.2639	.0932
11.	.2639	.0736
12.	.2639	.0581
13.	.2639	.0459
14.	.2639	.0362
15.	.2639	.0286
16.	.2639	.0226
17.	.2639	.0179
18.	.2639	.0141
19.	.2639	.0111
20.	.2639	.0088
21.	.2639	.0069
22.	.2639	.0055
23.	.2639	.0043
24.	.2639	.0034
25.	.2639	.0027
26.	.2639	.0021
27.	.2639	.0017
28.	.2639	.0013
29.	.2639	.0011
30.	.2639	.0008
31.	.2639	.0007
32.	.2639	.0005
33.	.2639	.0004
34.	.2639	.0003
35.	.2639	.0003
36.	.2639	.0002
37.	.2639	.0002
38.	.2639	.0001
39.	.2639	.0001
40.	.2639	.0001
41.	.2639	.0001
42.	.2639	.0000
43.	.2639	.0000
44.	.2639	.0000
45.	.2639	.0000
46.	.2639	.0000
47.	.2639	.0000
48.	.2639	.0000

Table II - 7

A= .840B= .730K= 2.400

A0= .8400 A1=-.9369 A2= .0969 B0=1.0000 B1=-.8810

J	Q(J)	T(J)
1.	1.1905	.8400
2.	.2790	.6432
3.	.1738	.5666
4.	.1617	.4992
5.	.1603	.4398
6.	.1601	.3875
7.	.1601	.3414
8.	.1601	.3008
9.	.1601	.2650
10.	.1601	.2335
11.	.1601	.2057
12.	.1601	.1812
13.	.1601	.1597
14.	.1601	.1407
15.	.1601	.1239
16.	.1601	.1092
17.	.1601	.0962
18.	.1601	.0848
19.	.1601	.0747
20.	.1601	.0659
21.	.1601	.0580
22.	.1601	.0511
23.	.1601	.0450
24.	.1601	.0396
25.	.1601	.0349
26.	.1601	.0309
27.	.1601	.0271
28.	.1601	.0239
29.	.1601	.0210
30.	.1601	.0185
31.	.1601	.0163
32.	.1601	.0144
33.	.1601	.0127
34.	.1601	.0112
35.	.1601	.0098
36.	.1601	.0087
37.	.1601	.0076
38.	.1601	.0067
39.	.1601	.0059
40.	.1601	.0052
41.	.1601	.0046
42.	.1601	.0041
43.	.1601	.0036
44.	.1601	.0031
45.	.1601	.0028
46.	.1601	.0024
47.	.1601	.0022
48.	.1601	.0019

Table II - 8

A= .340 Q= .590 K= 2.400

A0= .8400 A1=******** A2= .2881 B0=1.0000 B1=-.8474

J	Q(J)	T(J)
1.	1.1905	.8400
2.	.5900	.4237
3.	.3840	.3591
4.	.3133	.3043
5.	.2891	.2579
6.	.2808	.2185
7.	.2779	.1852
8.	.2769	.1569
9.	.2766	.1330
10.	.2765	.1127
11.	.2765	.0955
12.	.2764	.0809
13.	.2764	.0686
14.	.2764	.0581
15.	.2764	.0493
16.	.2764	.0417
17.	.2764	.0354
18.	.2764	.0300
19.	.2764	.0254
20.	.2764	.0215
21.	.2764	.0182
22.	.2764	.0155
23.	.2764	.0131
24.	.2764	.0111
25.	.2764	.0094
26.	.2764	.0080
27.	.2764	.0068
28.	.2764	.0057
29.	.2764	.0049
30.	.2764	.0041
31.	.2764	.0035
32.	.2764	.0030
33.	.2764	.0025
34.	.2764	.0021
35.	.2764	.0018
36.	.2764	.0015
37.	.2764	.0013
38.	.2764	.0011
39.	.2764	.0009
40.	.2764	.0008
41.	.2764	.0007
42.	.2764	.0006
43.	.2764	.0005
44.	.2764	.0004
45.	.2764	.0003
46.	.2764	.0003
47.	.2764	.0002
48.	.2764	.0002

Table II - 9

A = .750[illegible]= .740K= 5.880

A0= .7500 A1=-.7556 A2= .0056 B0=1.0000 B1=-.5585

J	Q(J)	T(J)
1.	1.3333	.7500
2.	.5786	.4133
3.	.5931	.2308
4.	.5931	.1289
5.	.5931	.0720
6.	.5931	.0402
7.	.5931	.0225
8.	.5931	.0125
9.	.5931	.0070
10.	.5931	.0039
11.	.5931	.0022
12.	.5931	.0012
13.	.5931	.0007
14.	.5931	.0004
15.	.5931	.0002
16.	.5931	.0001
17.	.5931	.0001
18.	.5931	.0000
19.	.5931	.0000
20.	.5931	.0000
21.	.5931	.0000
22.	.5931	.0000
23.	.5931	.0000
24.	.5931	.0000
25.	.5931	.0000
26.	.5931	.0000
27.	.5931	.0000
28.	.5931	.0000
29.	.5931	.0000
30.	.5931	.0000
31.	.5931	.0000
32.	.5931	.0000
33.	.5931	.0000
34.	.5931	.0000
35.	.5931	.0000
36.	.5931	.0000
37.	.5931	.0000
38.	.5931	.0000
39.	.5931	.0000
40.	.5931	.0000
41.	.5931	.0000
42.	.5931	.0000
43.	.5931	.0000
44.	.5931	.0000
45.	.5931	.0000
46.	.5931	.0000
47.	.5931	.0000
48.	.5931	.0000

Table II - 10

A = .750 B = .710 K = 5.880

A0= .7500 A1=-.7638 A2= .0138 B0=1.0000 B1=-.3445

J	S(J)	T(J)
1.	1.3333	.7500
2.	.8985	.2446
3.	.8905	.0843
4.	.8904	.0290
5.	.8904	.0100
6.	.8904	.0034
7.	.8904	.0012
8.	.8904	.0004
9.	.8904	.0001
10.	.8904	.0000
11.	.8904	.0000
12.	.8904	.0000
13.	.8904	.0000
14.	.8904	.0000
15.	.8904	.0000
16.	.8904	.0000
17.	.8904	.0000
18.	.8904	.0000
19.	.8904	.0000
20.	.8904	.0000
21.	.8904	.0000
22.	.8904	.0000
23.	.8904	.0000
24.	.8904	.0000
25.	.8904	.0000
26.	.8904	.0000
27.	.8904	.0000
28.	.8904	.0000
29.	.8904	.0000
30.	.8904	.0000
31.	.8904	.0000
32.	.8904	.0000
33.	.8904	.0000
34.	.8904	.0000
35.	.8904	.0000
36.	.8904	.0000
37.	.8904	.0000
38.	.8904	.0000
39.	.8904	.0000
40.	.8904	.0000
41.	.8904	.0000
42.	.8904	.0000
43.	.8904	.0000
44.	.8904	.0000
45.	.8904	.0000
46.	.8904	.0000
47.	.8904	.0000
48.	.8904	.0000

A= .2100= .5100= 5.600

A0= .7100 A1=-.2303 A2= .1293 [illegible]=1.00[illegible] W1=-.6463

[illegible]	[illegible]	[illegible]
1.	.6933	.7190
2.	.7344	.3294
3.	[illegible]	[illegible]
4.	.6133	.1377
5.	.6092	.0890
6.	.6092	.0675
7.	.6090	.0372
8.	.6090	.0240
9.	.6090	.0155
[illegible]	.6090	[illegible]
11.	.6090	.0065
12.	.6090	.0042
13.	.6090	.0027
14.	.6090	.0018
15.	.6090	.0011
16.	.6090	.0007
17.	.6090	.0005
18.	.6090	.0003
19.	.6090	.0002
20.	.6090	.0001
21.	.6090	.0001
22.	.6090	.0001
23.	.6090	.0000
24.	.6090	.0000
25.	.6090	.0000
26.	.6090	.0000
27.	.6090	.0000
28.	.6090	.0000
29.	.6090	.0000
30.	.6090	.0000
31.	.6090	.0000
32.	.6090	.0000
33.	.6090	.0000
34.	.6090	.0000
35.	.6090	.0000
36.	.6090	.0000
37.	.6090	.0000
38.	.6090	.0000
39.	.6090	.0000
40.	.6090	.0000
41.	.6090	.0000
42.	.6090	.0000
43.	.6090	.0000
44.	.6090	.0000
45.	.6090	.0000
46.	.6090	.0000
47.	.6090	.0000
48.	.6090	.0000

Table II - 12

A= .710B= .300K= 5.880

A0= .7100 A1=-.9513 A2= .2413 B0=1.0000 B1=-.5886

J	Q(J)	T(J)
1.	1.4085	.7100
2.	1.0582	.1766
3.	.9391	.1039
4.	.8987	.0612
5.	.8849	.0360
6.	.8802	.0212
7.	.8787	.0125
8.	.8781	.0073
9.	.8779	.0043
10.	.8779	.0025
11.	.8779	.0015
12.	.8778	.0009
13.	.8778	.0005
14.	.8778	.0003
15.	.8778	.0002
16.	.8778	.0001
17.	.8778	.0001
18.	.8778	.0000
19.	.8778	.0000
20.	.8778	.0000
21.	.8778	.0000
22.	.8778	.0000
23.	.8778	.0000
24.	.8778	.0000
25.	.8778	.0000
26.	.8778	.0000
27.	.8778	.0000
28.	.8778	.0000
29.	.8778	.0000
30.	.8778	.0000
31.	.8778	.0000
32.	.8778	.0000
33.	.8778	.0000
34.	.8778	.0000
35.	.8778	.0000
36.	.8778	.0000
37.	.8778	.0000
38.	.8778	.0000
39.	.8778	.0000
40.	.8778	.0000
41.	.8778	.0000
42.	.8778	.0000
43.	.8778	.0000
44.	.8778	.0000
45.	.8778	.0000
46.	.8778	.0000
47.	.8778	.0000
48.	.8778	.0000

Appendix D

U. S. - French Cooperative Program in Building Technology

Proposal for Future Activities on Environmental Engineering After Dr. Kusuda's Stay at C.S.T.B. During July, 1970

1. <u>Use of C.S.T.B. Analog Computer to Supplement the Digital Computer Work of N.B.S.</u>

   1.1 C.S.T.B. would provide N.B.S. the room temperature weighting factors for the digital computer. The use of the analog computer is to expedite the calculation to account for the room heat capacity (partitions, floors, ...) in the case inside temperature is varying.

   1.2 N.B.S. would provide current information on system simulation in U.S.A. (including characteristics of components) to C.S.T.B. so that C.S.T.B. can start a similar simulation program on their analog computer.

   1.3 C.S.T.B. would help N.B.S. in taking account of environments control system in the building thermal calculation by digital computer.

2. <u>Climatological Data</u>

   2.1 C.S.T.B. would provide N.B.S. one sample apparatus for measuring long wave radiation. As a start C.S.T.B. would furnish drawings and schematic diagrams of the apparatus.

   2.2 N.B.S. desires data for diffuse sky radiation during cloudy days. C.S.T.B. would explore possibilities of extracting such data for their future solar radiation studies.

2.3 N.B.S. would provide to C.S.T.B. their studies on earth temperature analysis.

3. <u>Convection Inside Rooms</u>

Work is currently in progress at N.B.S. and is foreseen at C.S.T.B.; other laboratories (specially C.E.D.R.I.C. in Liege) have also been active in this field.

Everyone will keep himself informed and will cooperate.

4. <u>Ventilation</u>

N.B.S. is interested in the ventilation processes used in French government sponsored low cost housing for the past years. C.S.T.B. will provide to N.B.S. useful information in this area.

5. <u>Overall Design of a Prototype Apartment Building Heated by Electricity (Building Designed Around Its Equipment)</u>

C.S.T.B. will provide N.B.S. background material for the general ideas of the studies, the choices, specially in matter of investment and consumption costs. N.B.S. will see to what extent the French prototype design will meet U. S. requirements. N.B.S. would explore the feasibility of including the prototype concept for the second phase of Operation Breakthrough (O.B.T.). If feasible, a joint study of N.B.S. and C.S.T.B. could be expected to adapt closely the French prototype design to U. S. requirement, particularly by incorporating inexpensive air cooling systems.

6. <u>Heat Pumps</u>

N.B.S. would provide C.S.T.B. a set of technical literature pertaining to the use of heat pumps.

N.B.S. would help to organize a stay of C.S.T.B. engineers in the United States to study heat pumps in dwellings.

7. <u>Solar Factor Standard</u>

N.B.S. would participate in preparing the standardized calculations of Solar Factors (S) planned by different European countries.

8. <u>Translations</u>

In the frame of translation program, C.S.T.B. will send to N.B.S.:

- two existing translations:

  Cahier n° 334: "Thermal weak points on cold bridges". (J. Berthier) - translated by N.R.C. Ottawa

  Cahier n° 608: "Protection of windows against solar radiation. Explanatory and analytical papers". (J. Anquez, J. C. Borel & M. Croiset) - translated by B.R.S. Garston

- three translations in progress:

  Cahier n° 455: "The effect of thermal weak points on the K coefficients of sandwich panels made of concrete and lightweight insulation". (J. Berthier & F. Clain)

  Cahier n° 468: "Protection of opaque panels by sun-breakers" (J. C. Borel)

  Cahier n° 910: "Summer comfort in light structure school buildings", (J. C. Borel), (livraison n° 104)

- two translations to be done: Title V (Thermic) and VIII (Ventilation) of C.S.T.B.'s Technical Advice (Notice Technique) concerning thermal problems and ventilation.

As soon as a new thermal study will be published by C.S.T.B. (cold bridges, heat exchanger, ...) it will be sent to the Environmental Engineering Section of N.B.S.

9. <u>C.S.T.B. Engineers Stays in the United States</u>

9.1 As Mr. Anquez will take part in the "Symposium on the Use of Computers for Environmental Engineering Related to Buildings" at N.B.S. during November 30 - December 2, 1970, it would be useful that Mr. Bertolo accompanies him and stays after the symposium for two or three weeks at N.B.S. to carry on the collaboration work begun at C.S.T.B. in July, 1970.

9.2 A short stay of one or two engineers (two or three weeks) devoted to heat pumps topics might occur in the spring of 1971; C.S.T.B. would prepare the program with N.B.S. help in order to firm up the details at the beginning of 1971.

10. <u>N.B.S. Engineers Stays in France</u>

N.B.S. would send one or two engineers for a period of two or three weeks to observe in depth the work being done in air convection at C.E.D.R.I.C. (Liege), in prototype design at C.S.T.B. (Paris, in physiological response at C.E.B. (Strasbourg), in cold bridge problems in prefabricated walls at C.S.T.B. and in thermal problems in light structure school buildings at C.S.T.B.

Proposed by:

Dr. T. Kusuda for N.B.S.
Mr. M. Croiset for C.S.T.B.

Paris, July 27, 1970

Appendix E

Visit to Technische Hogeschool, Delft (TNO-TH), Holland

The author was met by Professor A. W. Boeke and Mr. P. Euser of the Mechanical Engineering Department (Werktnigbouwkunde); both of them have been active in the use of computers for the environmental engineering calculation. Prior to joining TH, Professor Boeke had been working with Svenske Flakt fabriken (a Swedish farm), where he developed several of the most widely used European computer programs for heating and cooling energy calculations. The details of the program were published in an article entitled "New Development in the Computer-Design of Air Conditioning Systems" in the October 1967 issue of JIHVE (Journal for the Institute of Heating and Ventilating Engineers). The program is to report a comprehensive energy use for typical days in a month for each of 12 months. The calculation for four typical days were so selected to represent sunny days and cloudy days of weekdays and holidays in addition to the design day calculation. The computation is carried on the module basis in that each module consists of many rooms with the same exterior wall characteristics. The program permits the evaluation of room temperature fluctuations as well as the room thermal response.

Mr. Euser is conducting analog computer simulations of Phitatron (environment controlled room for the plant) and said that the analog system is still useful for the detailed study on control simulation. The simulation included the simultaneous transfer of heat and moisture at the plant surface and soil surface. This research is done at TNO (Applied Scientific Research) under the contract from the Ministry of Agriculture.

Appendix F

Visit to the Building Research Station (England)

On July 31, the Environmental Design Engineering Division of the Building Research Station (England) was visited. The Division is the equivalent of our Sensory Environment Branch but much larger in staff (66) and activities (9 sections). The author was received by Messrs N. Milbank and P. Petherbridge in the morning to discuss their energy usage analysis and computer applications. They have studied several commercial buildings with respect to their weekly energy usage and found that the major portion of the energy was spent for the lighting and energy distribution (pump and fans) and that accounted for heating and cooling was rather small. They are currently continuing this survey effort and have added a task to include the survey of expense for the maintenance of equipment by sending standard questionnaires to the operators of 30 buildings. They are finding that with some scatter the maintenance cost and the energy usage cost are both 4 shillings per square foot (70% of gross floor area). Their computer activities are, however, just beginning and they have recently completed a program to obtain solar energy tables. Mr. Petherbridge told the author that Mr. Billington of the Heating, Ventilating Research Association has been active in the use of computers for energy calculation. Mr. Billington has recently made comparative analysis of Westinghouse, APEC, Phillips, SF and Faber computer programs on a fictitious building. The maximum thermal load calculated by these programs varied widely (watts/m^2 of floor ranging from 3000 to 5000).

In the afternoon, the author was met by Mr. Loudon who has been active in heating and ventilating research. Mr. Loudon is currently studying natural ventilation of school buildings as affected by outdoor wind velocity. This study is being conducted in a room (2.53m x 2.55m x 2.46m) in a rotatable experimental building with the use of tracer gas (N_2O and SF_6). They found that N_2O is less harmful than CO_2 and think that SF_6 should be even better for the study.

The natural convection study with the use of metaldehyde in a transparent room reported by Mr. Daw in their previous research report was terminated long ago. Mr. Sexton's group is still continuing the use of the wind tunnel for the study of air flow around multiplicity of commercial buildings. They are now finding that the porosity of the building seems to alter the flow characteristics. This is interesting from the standpoint of correlating the outdoor air velocity profile with the air infiltration characteristics of the building.

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