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Techniques for the Survey and Evaluation of Live Floor Loads And Fire Loads in Modern Office Buildings

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Techniques for the Survey and Evaluation of Live Floor Loads and Fire Loads in Modern Office Buildings

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Building Research Division
Institute for Applied Technology
National Bureau of Standards
Washington, D.C.

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Techniques for the Survey and Evaluation of Live Floor Loads and Fire Loads in Modern Office Buildings

J. O. Bryson and D. Gross

The procedures and techniques developed for measuring and evaluating the live floor loads and fire loads in modern office buildings are summarized. The main features of a computer program for analyzing the data are outlined. This program provides a tabulation of the data, some statistical properties, and selected graphical relationships between the measured loads and the characteristics and usage of the structure. A rationale is developed which is intended to achieve the ultimate goal—easier and less expensive means of surveying live loads in buildings and their combustible content.

Two office buildings have been surveyed in a pilot evaluation of the survey techniques—the National Bureau of Standards Administration Building in Gaithersburg, Maryland, and the U. S. Civil Service Commission Building in downtown Washington, D. C. Typical results are presented to illustrate the computer output.

Key Words: Fire loads, live floor loads, loads survey techniques, occupancy loads.

1. Introduction

A survey of loads in modern office buildings was initiated in February 1967 as the first step in a broad program developed at the National Bureau of Standards to scientifically study existing loads on structures. The first phase of the program is concerned with measurement of actual live floor loads and fire loads. The central objective of the first part of this program is to develop survey techniques and procedures for easier and less expensive means of surveying loads on buildings, and to develop evaluative measures, in line with present day technology of scientific methods, for determining the nature of the loads in relation to the characteristics of the load items and in relation to the geometry of the structure.

In the structural design of a building the engineer has three principal concerns, the analysis of the structural system, the strength of the materials in the system, and the loads to which the structure will be subjected. Extensive scientific knowledge exists on the characteristics of structural systems and the properties of materials due to broad and continuing research in these areas. In contrast to this, very little is known about the actual loads that are applied to structures. The few studies that have been made in the past [1–7]* have not been of sufficient scope to provide comprehensive data that could serve as a scientific basis for establishing design criteria. Comprehensive data on actual loadings could result in a reduction of design loads specified in codes and standards. Even where higher design loads are shown to be needed, gains in economy could still be realized, since more accurate information about loads could justify a reduction in safety factors.

With respect to fire loads, there is a need to update and to extend the survey of combustible contents of buildings made approximately 30 years ago [8, 9]. Although significant changes have occurred in the type of building construction and the nature of the occupancy load, fire protection measures currently required in building construction are based on the assumption of the same fire loads as previously observed.

The field studies carried out in the past were of necessity limited in scope; consequently, a relatively small sample size of data was obtained from which to draw conclusions about the vast population of buildings. The main purpose of this current work is to develop, for the first time, a sufficiently large bank of comprehensive data that can be used to predict, with measured accuracy, the live floor loads and fire loads for various building occupancy types in this country.

This paper summarizes the procedures and techniques developed to date for the weighing and classification of items and for the analysis of live floor loads and fire loads in modern office buildings. As an illustration, the loads measured within two modern Government-owned office buildings in the Washington, D. C., area are included. It is planned that these results will eventually form part of a large collection of data from surveys of buildings located in the major regions across the country.

* Figures in brackets indicate the literature references on page .

2. General Approach

The first phase of the survey was considered to be a pilot study which would provide an opportunity to perfect the techniques and survey procedures and to serve as a training exercise for survey crews. A principal objective was to accumulate data and experience which could lead to easier and less expensive ways of surveying loads in buildings. For example, it may be possible to classify furniture into a number of types and sizes, and its contents by volume, either in cubic feet or percent of capacity, so that little or no weighing will be necessary to obtain weight estimates in the future.

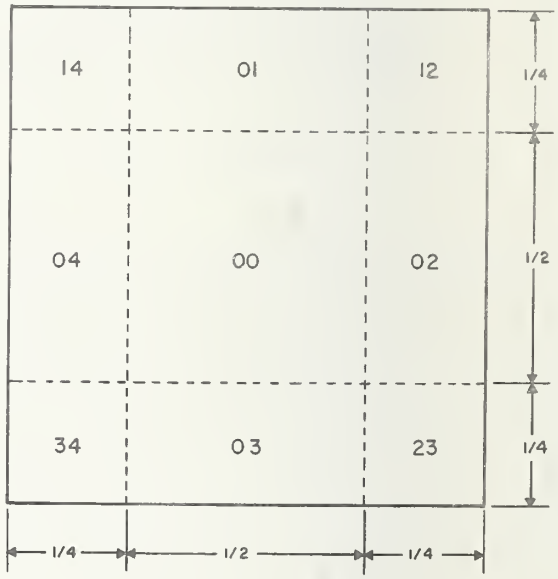
The survey is presently being limited to modern buildings, i.e., buildings erected within the past 10 years. Since the occupancy load is likely to change appreciably over the years, supplementary load data on older buildings may also be needed. One consideration in the choice for the initial survey was the availability of the building for resurveys in future years. Accordingly, the National Bureau of Standards Administration Building and other Government buildings in the Washington, D. C., area represent logical buildings for possible periodic load surveys.

3. Survey Techniques and Procedures

3.1. General

The techniques and procedures for measuring and recording the data from occupancy loads were developed in accordance with plans established for a broad NBS program designed to evaluate existing live floor loads and fire loads in office buildings. The load data obtained with the techniques used provide singular source type input information for both live load and fire load data analysis. The actual survey work for this preliminary phase of the study represents the first step of a program in which statistical analysis of the data will serve as the foundation for succeeding steps leading to statistical sampling techniques.

In the two buildings surveyed, the weights and the approximate horizontal locations of all the items in each room were determined and recorded. Floor plans of the buildings were used to note room layouts and locations and were corrected, if necessary, to reflect actual conditions. These plans were maintained with other records for the investigation. All data were coded and recorded in a format consistent with an appropriate computer program for automatic data processing. In each case the room was divided into nine sections and defined by three strips in each direction parallel to the wall and perpendicular to each other. The width of the center strip was one-half the distance between the walls that it parallels and the strips to either side were one-quarter of the distance between the walls. These strips then correspond to the midstrips and column strips of a two way flat slab where the boundaries of the room serve as the column line. The overlapping of the strips in the two directions, form a checkered pattern of areas which provides a general location scheme (see fig. 1).



Code number is related to an actual direction, e.g.:

00 = Central	03 = South
01 = North	34 = Southwest
12 = Northeast	04 = West
02 = East	14 - Northwest
23 = Southeast	

FIGURE 1. *General scheme for locating items within the room.*

3.2. Definition of Survey Loads

The live loads in the survey include the occupants, the floor covering, movable partitions, all furniture and equipment and their contents, except built-in items. Built-in items are those whose shape and size were designed as an integral part of the structure and were formed during construction of the buildings. The furniture and equipment brought in for the service of the occupants after the construction of the building (including those which are placed in recesses and/or tied down in the structure)

were not considered built-in and their weights were determined (or estimated).

The fire load falls into two general categories—"movable contents" and "interior finish." Movable contents include combustible furniture, equipment, and goods, and the combustible contents within and on top of items including metal furniture and containers. Also included were floor coverings not securely fastened to the floor. The remainder of the combustible load associated with rooms and buildings consisted of the "interior finish fire load" and comprised walls, ceilings, floors (including permanently installed wall-to-wall carpeting and finish flooring), drapery, wall hangings, partitions, door and window trim, and built-in fixtures (e.g., bookcases). Where such items could not be weighed, their weights were estimated from thickness and area. As an aid in estimating, a "combustible trim list" was prepared containing weights for typical sizes of doors, windows, molding, and lumber. A "building materials list" was also prepared which provided a rapid means for converting measured or estimated thicknesses of typical interior finish materials into equivalent unit weights of combustibles. For common doors, one-half the total weight was assigned to the respective room on each side.

All weights were converted to equivalent weights of combustibles having a calorific value of 8000 Btu/lb. Tables of calorific values of materials can be found in standard reference sources. A list of heat release values for building materials under "fire" conditions is also available [10] and is particularly useful for metals and materials of low combustibility.

The movable contents fire load has been further divided into separate totals of "free" movable contents and "adjusted" movable contents. The "free" movable contents fire load represents materials readily available for combustion, and includes combustible furniture and their combustible contents, combustibles on top of steel desks and tables, and those associated with miscellaneous and "free contents" items. It excludes combustibles within enclosed steel furniture, such as shelving, filing cabinets, desks, and safes. The "adjusted" movable contents fire load represents the "free" movable contents fire load plus the "effective" contribution of the combustible contents of steel furniture, computed in accordance with the "derating" values in table 1, based on BMS 92. These values have been (customarily) assumed to depend only on the relative portion of combustibles within a room which are located in steel furniture. However, the degree of compaction within individual file cabinets, shelving, desk drawers, etc., may also modify its effective contribution.

Estimates of the volume of combustible contents on top, rather than measured weights,

Table 1. *De-rating factors to determine combustible contents of steel furniture*
(Based on Table 6, BMS 92)

Container	Part of combustibles in containers		
	Less than one-half	One-half to three-fourths	More than three-fourths
	%	%	%
Enclosed steel shelving	60	50	25
Steel file cabinets and desks	40	20	10
Insulated (1 hr fire-rated files & safes)	0	0	0

were used to determine the "free" movable contents portion of desks and tables. In converting the volume estimate to weight, a density of 40 lb/ft^3 was assumed. A volume estimate was made of the contents of desks, cabinets, and bookcases, and note made of the nature of its contents (100% books, 100% paper or mixed). For desks and cabinets, an estimate was also made of the contents volume, expressed as a percent of its capacity. With these measurements and estimates, the "derating" factors for steel furniture were applied, and data were assembled for correlating the combustible weight of contents (paper or books) with the capacity of standard desks and cabinets (by percent) and of bookcases (by volume). For miscellaneous steel furniture, the empty weight was unknown and volume estimates provided a means for estimating the weight of combustible contents.

3.3. Data Records and Classification

The survey data included code input designations for floor level, room number, room use, overall dimensions, number of assigned personnel and sex, item weight, location, and description, and a description and measurement of the contents in items. The locations of the items in a room were recorded with respect to the nine sections defined for room area. In addition, surface finish and the weights of trim and floor covering were recorded. A typical log sheet with entries is shown in figure 2 and a schematic representation of the items listed on the log sheet is seen in figure 2A. From this log sheet, a single "room" card and the required number of "item" cards were keypunched directly without further conditioning or special handling. Rooms were designated in one of the following use categories: office, laboratory, storage, conference room, lounge, lobby (or reception room), dining room, library, file room, and "other." The length, width, and height of the room were recorded to the nearest foot, with an area reduction en-

LOADS SURVEY LOG SHEET

Building_____ Date_____

Room Number	Floor Level	Room Use	N-S Dimension	E-W Dimension	Height	Number of Personnel Male	Number of Personnel Female	Number of Items	Surface Finish Floor	Surface Finish Ceiling	Surface Finish N Wall	Surface Finish E Wall	Surface Finish S Wall	Surface Finish W Wall	Weight of Trim	Weight of Floor Covering	Area Reduction	Notes
A2713	020	1	015	025	12	02	00	16	4	3	1	1	1	1	000	000	00	

Item Number	Item Code	Location	Base Area Code	Misc. Item Base Area, Sq. In.	Total Weight	Contents Non Comb. Weight	Contents Category	Contents Measurement Percent of Capacity	Contents Measurement Cubic Feet	Combustible Contents on Top, Cu. Ft.	Notes
01	0102	12	1	—	0352	0018	3	06	—	1.5	
02	0201	02	1	—	0123	0005	3	—	—	1.0	
03	0326	23	1	—	0217	—	1	05	—	—	
04	0001	01	0	—	0011	—	3	—	—	—	FREE CONTENTS-BASE AREA ALWAYS ZERO
05	0520	14	1	—	0331	—	2	—	3.0	—	
06	0010	12	0	—	0006	0006	—	—	—	—	EMPTY WASTE BASKET-BASE AREA ALWAYS ZERO
07	0405	12	1	—	—	—	—	—	—	—	CHAIR-BASE AREA & EMPTY WT. STORED IN COMPUTER
08	0400	01	1	—	—	—	—	—	—	—	" " " "
09	0400	14	1	—	—	—	—	—	—	—	" " " "
10	0405	00	1	—	—	—	—	—	—	—	" " " "
11	0403	02	1	—	—	—	—	—	—	—	" " " "
12	2198	00	1	1500	0365	0015	3	—	1.5	0.5	MISCELLANEOUS METAL DESK
13	1398	03	1	0300	0197	0002	1	—	2.0	—	MISCELLANEOUS WOOD FILE CABINET
14	0510	03	0	—	0091	—	2	—	1.0	—	BOOKCASE SECT. ON TOP OF ITEM NO.13
15	2398	03	1	0320	0215	0005	1	06	2.0	—	MISCELLANEOUS METAL FILE CABINET
16	2399	04	1	0320	0518	—	1	08	3.0	—	MISC. METAL FILE CABINET-FIRE RATED 1 HR.

FIGURE 2. *Typical log sheet.*

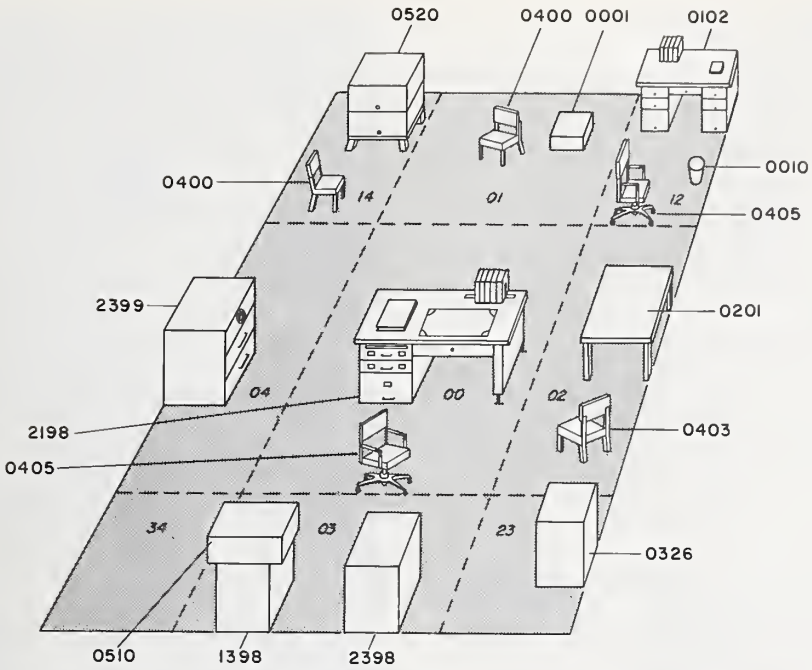


FIGURE 2-A. *Schematic representation of items listed on typical log sheet (figure 2).*

try in square feet to allow for recess areas.

Each item was assigned a four-digit numeric code and was classified into one of six categories: desks (0100 series), tables (0200), cabinets (0300), chairs (0400), bookcases (0500), or miscellaneous (0001 to 0099). A reference catalog of the basic "standard" items of office furnishings was prepared prior to starting the survey, and was augmented with new items encountered in the survey. The catalog entry included a photograph of the item, the assigned code number, dimensions, composition, empty weight, and other pertinent descriptive information. A detailed description of the coded records is given in Appendix A.

3.4. Survey Team

A team of four men performed the survey work. The team leader defined the items, recorded the data, and took photographs. Two men handled the weighing equipment and did the measuring of dimensions. The fourth man estimated combustible contents.

FIGURE 3. *Electronic load platforms used as the sensing element in all weighing operations.*

3.5. Equipment

The weighings were made with the use of electronic load platforms. These devices are rectangular plates that were designed to indicate the load that is applied normal to its surface within a specified area (see fig. 3). Two load platforms were used in the survey. One platform was 26-in long by 14-in wide with a 20×14-in loading area and the other platform was 32-in long by 14-in wide with a 26×14-in loading area. Both platforms were approximately 1-in in height. Two units of item handling equipment were used for lifting room furnishings. Both units were standard equipment purchased from commercial sources. For both units, load indications were linear with load over the load range, and accuracy as read was estimated to be within 2 percent. One unit was a desk handler, figure 4, and the other was

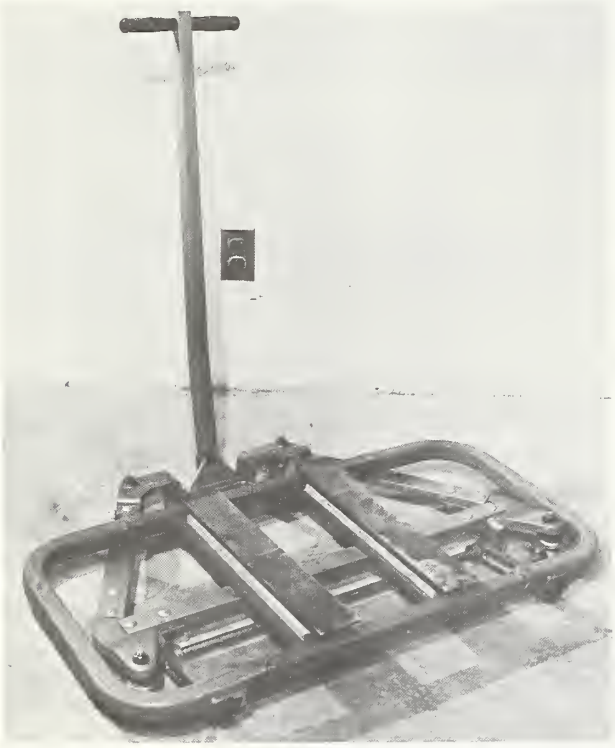


FIGURE 4. *Commercial type desk handler with modified central braces to support load platform.*

a hydraulic forklift, figure 5. Figure 6 shows views of these units with load platforms positioned on them so that weighings were made in conjunction with the lifting operation. A list of all the equipment and supplies for the survey operation is given below and a view is presented in figure 7.

List of Equipment and Supplies for Survey Team

1. Hydraulic fork truck
2. Desk handler

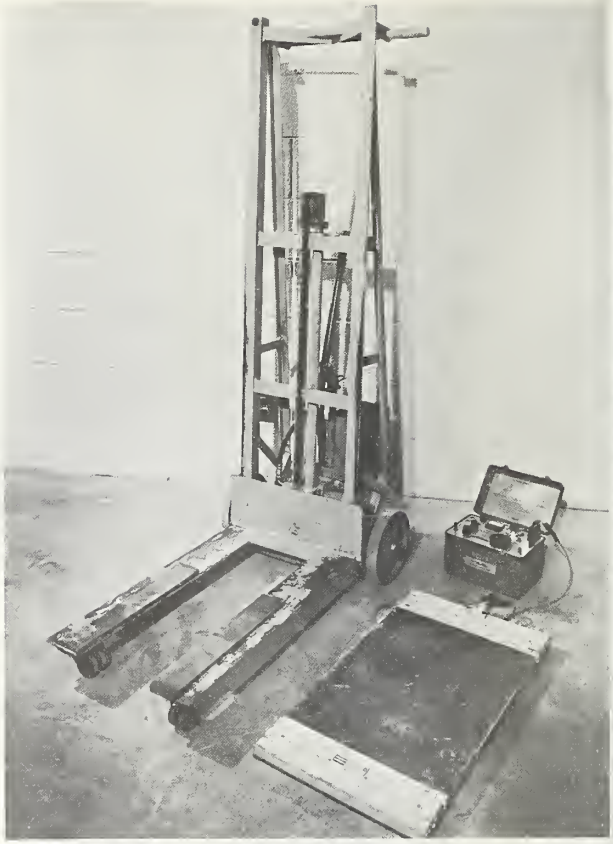


FIGURE 5. *Forklift actuated through hydraulic pump system.*

3. 2 steel plates
4. 2 load platforms
5. 1 readout box
6. Assortment of 2×4-in wood bearing strips (18 in, 24 in, 48 in, and 2 72-in-long strips)
7. Hand truck
8. Chain and padlock
9. Large clipboard
10. Survey sheets and envelopes
11. Red, blue, green pens (ball point and felt tip)
12. 12 and 50 ft tapes
13. Slide rule
14. Camera, film, flashbulbs (Polaroid, color)
15. Floor plans of buildings
16. Tool kit—pliers, screwdriver, solder, etc.
17. Calibrating weights

3.6. Survey Procedure

The order of floor levels in the survey was random; however, for the most part rooms on a given floor were surveyed in numerical order according to room number.

Before starting the survey, the survey team was briefed and drilled on the techniques and

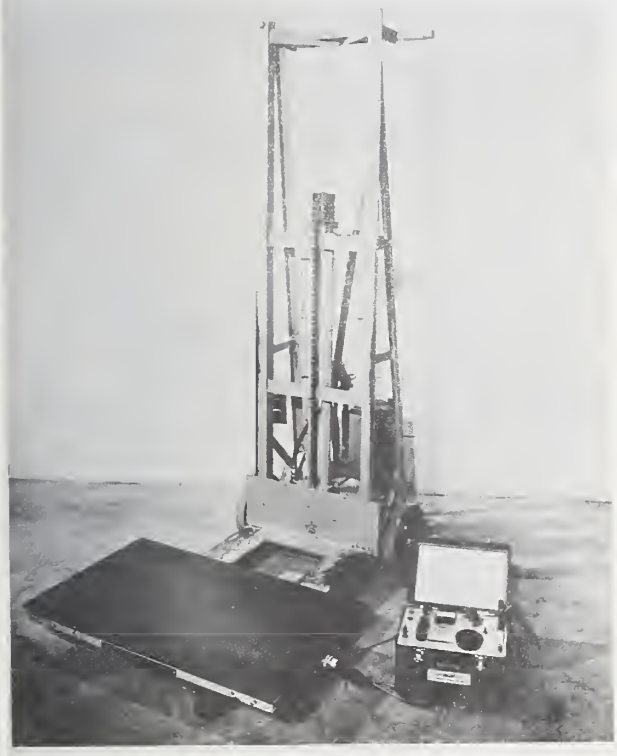


FIGURE 6. Top: *Desk handler with load platform positioned for use.* Bottom: *Forklift with load platform inserted across the arms and a flat metal plate on top.*

procedures to be followed. The manner of coding and recording the data was thoroughly explained and discussed. The team leader was given an item code list and an instruction sheet for location code.

Just prior to surveying a room, the team leader recorded the floor level, the room number, room use (e.g., office, storage, etc.), and the number of assigned personnel—indicating sex. The two assistants were then called into the room with the team leader to take measurements in the room. The weighing equipment was left outside the room while measurements of the room were being made. The dimensions of the room were measured by the two assistants and recorded on the record form by the team leader. The equipment for weighing was then brought in and the items in the room weighed in an order determined by the team leader. It was found that in a few cases an item and its contents could not be weighed together, as in the case of tall or fragile items that were not designed to be moved when full; therefore, in these cases contents were weighed separately from the item. For each item, a separate weight of the noncombustible portion of the contents was determined and recorded by the team leader. For items that could not be weighed either because of size, weight, or sensitivity or because they were tied down, the weights were obtained from the manufacturers or were estimated. The types of surface finish and their thickness were determined by the team leader, who used a material type listing to select the appropriate unit weight range in terms of combustibles.

All items were weighed using the load platform and the item handling unit, desk lifter, or hand forklift, whichever was best suited for the particular case. Figures 8 and 9 show views of weighing operations during the survey. The exception to this was the weighing of a file cabinet for which a set procedure was established using only a load platform and a wood bearing strip. The following is a detailed description of the procedure in the form of instructions to the survey team which was used throughout the survey.

In most cases, file cabinets will be found backed against a wall, either standing alone or in groups placed closely together. The procedure that will be used to weigh these items is designed to minimize strenuous handling in the weighing operation. Two men will be needed to perform the task. The units will be weighed with the load platform positioned on the floor. First, the cabinet will be slid out from the wall 12 inches or more. Next, place the load platform on the floor directly in front of the cabinet with the long dimensions of both objects in line. Place the short length wood bearing strip (2×4-in) on its broad side on the load platform positioned within the loading area parallel to the front of the file cabinet. (See figure 10 top). Tilt the file cabinet back so that the front edge of the bottom surface will be raised 5 or 6 inches off the floor. Slide the platform straight forward under the cabinet until the wood bearing strip is located near the center of the bottom surface of the cabinet. Lean the cabinet forward to make contact with the bearing strip on the load platform and rock the cabinet to an upright position. (See fig. 10 bottom). If the cabinet is not balanced on the bearing strip, apply with the hand the necessary force in a horizontal direction to maintain the cabinet in an upright position while the load indicator is being read. The cabinet shall be removed from the load platform and replaced in its original location by reversing the handling operation leading up to weighing.

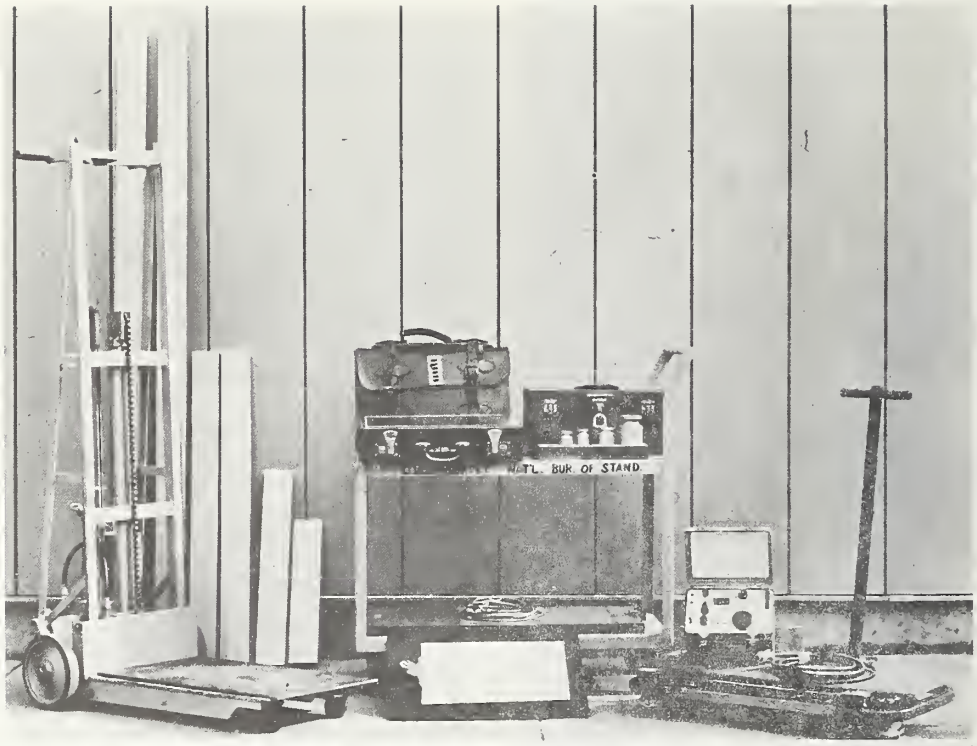


FIGURE 7. *Equipment and supplies for survey work.*

3.7. Measurements of Contents in Selected Items

The weight of all of the contents found in a room was determined by weighing. The noncombustible portion of the contents was estimated directly in pounds. The amount of the combustible contents associated with selected items was estimated either as a percentage of the total capacity of the item to hold paper, or as volume of contents in cubic feet, or both, depending on the type of item. Specific examples follow:

1. Desk
   (a) Regular type—estimated the total amount of combustible contents on top and inside as a percentage of the volume capacity of the drawers. Also, estimated the volume of combustible contents on top in cubic feet.
   (b) Miscellaneous metal type—separate estimates of the volume of combustible contents both on top and inside were made in terms of cubic feet.
2. File Cabinets
   (a) Regular type—estimated the total of combustible contents as a percentage of the volume capacity of the drawers. Contents on top of the item were considered unassociated and were designated free contents (code = 0001).
   (b) Miscellaneous type—estimated the total amount of combustible contents in cubic feet.
3. Bookcases
   For all bookcases, estimated the amount of combustible contents within the case in cubic feet.

4. Computer Program for Data Analysis

A flexible computer program in Fortran IV language was written to analyze the data and to provide outputs in tabular and graphical form. The program can handle a maximum of 900 rooms from a given building or from a combination of buildings, making maximum usage of the 65,000 storage cells of a UNIVAC 1108 computer. Use is also made of available subroutines for statistical analysis, frequency, and plotting. The time for a complete run is approximately $19 + 2.6\ N$ seconds, where N equals the number of rooms. An auxiliary program is used to check the input data for obvious errors or missing entries. Further details are given in Appendix B.

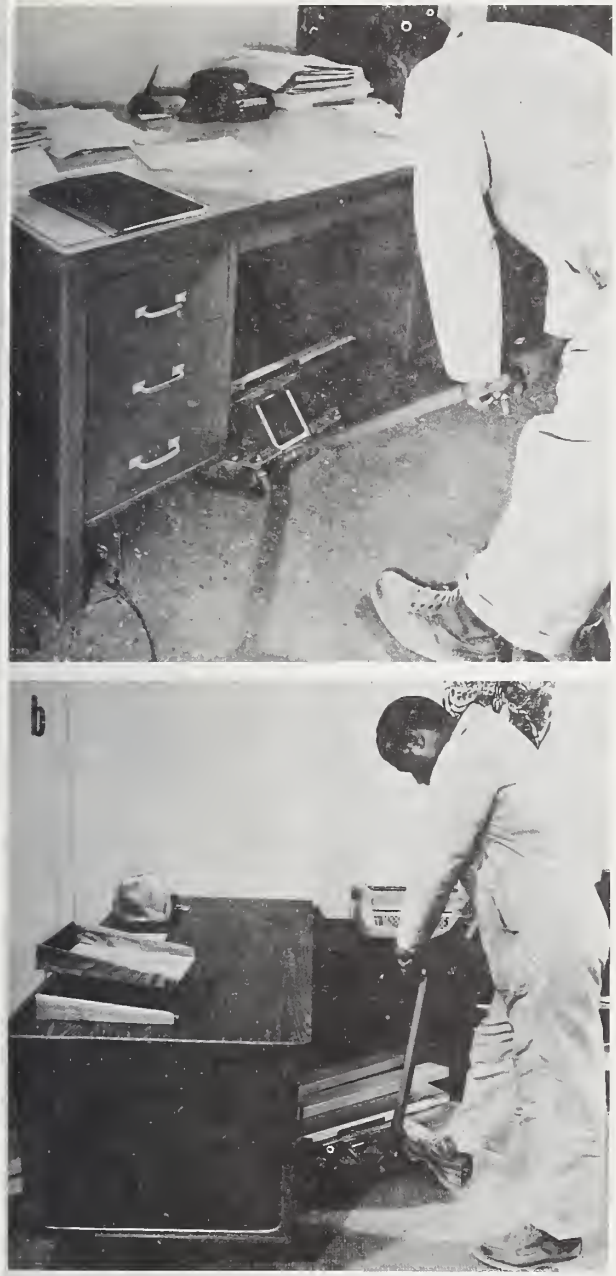


FIGURE 8. *Weighing techniques for desks.*

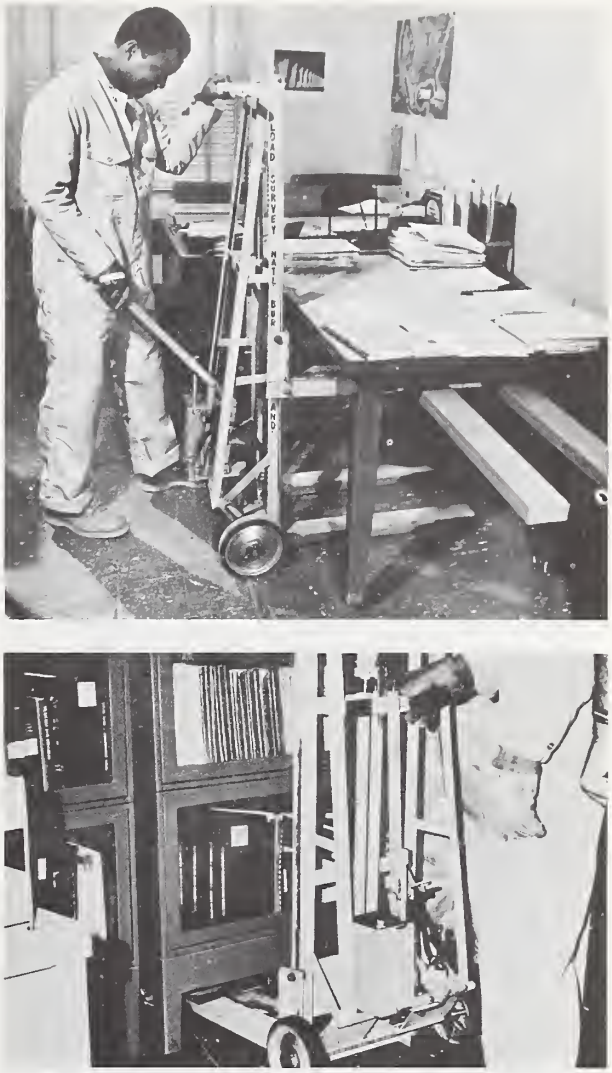


FIGURE 9. *Weighing techniques for tables and bookcases.*

5. Application of Techniques—Initial Survey Results

To date, load surveys have been conducted in two office buildings. The NBS Administration Building, located at Gaithersburg, Maryland, is an 11-story reinforced concrete 45 by 225 ft building of rectangular shape completed in 1965. Except for the basement and utility rooms, it was surveyed completely from February to May 1967. The area surveyed covered 70,820 ft^2 in 335 rooms. Of this 53,689 ft^2 or 252 rooms were offices. The U.S. Civil Service Commission Building, FOB (Federal Office Building) No. 9, located at 19th, 20th, D and E Streets, N.W., Washington, D.C., is a 7-story reinforced concrete H-shaped structure completed in 1963. A sampling of 55,130 ft^2 of space (48,407 ft^2 office), considered to be representative of its 573,000 ft^2 total, was surveyed in July 1967. The total area surveyed was 125,950 ft^2 covering 556 rooms. According to room usage category, there were 453 office,

FIGURE 10. *Weighing a file cabinet.*

8 laboratory, 26 storage, 22 conference, 1 lounge, 8 lobby, 13 library, 5 file, and 20 rooms classified as other. The NBS building was surveyed at an average rate of 430 ft^2/hr. The CSC building was surveyed at an average rate of 590 ft^2/hr. These rates reflect the tedious detailed work in the pilot study needed to develop the survey techniques and procedures and to set a firm foundation for the advanced survey methods.

Based upon experience gained in surveying the NBS Administration Building, significant changes were made in the survey procedure for FOB 9. These included adding estimates of combustible contents on top of desks and tables, and within miscellaneous files, combining items of similar type and weight, and substituting a volume estimate for a linear measurement of contents. Because of this, and the fact that two buildings may not represent a true sampling of office building types and use conditions, these results are to be considered as preliminary.

The output is in the form of 15 tables and 10 sets of graphs (see list, Table B–1 of Appendix B) which should provide meaningful information on the individual items and their relation to the geometry of the structure. These include:

(1) The average weight of a file cabinet, desk, bookcase, etc.

(2) The frequency distribution of weight and combustible content for these items.

(3) The average amount of its contents.

(4) The discrete unit load (weight of item/base area of item) for each item.

(5) The distribution of loads on floor sections.

(6) The variation of loads by floor level.

(7) The percentage of space occupied by load items.

(8) The distribution of loads by room area.

Some of the results from the pilot study are presented only to illustrate the type of computer output that was developed as a first order statistical evaluation of the data. The results are presented in tables 2 through 6 and figures 11 through 24.

Table 2 shows the distribution by room usage of the mean movable contents, interior finish, and total fire loads for the two buildings. The movable contents portion is listed both in pounds per square foot and expressed as a percent of the total load (combustible and noncombustible). Also shown for FOB 9 are the separate listings of the mean values of "free" and "adjusted" movable contents fire load. The total fire load is the sum of the movable contents and the interior finish fire loads, without adjustments. Table 3 lists the percentage of combustible contents within three types of enclosed steel furniture.

Table 4 gives the equivalent uniformly distributed load for each floor level in both buildings surveyed. The first six floor levels are those for FOB 9 and the following 11 are for the NBS building. The bottom line shows a distributed load for the two buildings.

Table 2. *Mean movable contents, interior finish and total fire loads*

Room usage	NBS Administration Bldg.					FOB 9						
	No. of rooms	Movable contents		Interior finish fire load	Total fire load	No. of rooms	Movable contents				Interior finish fire load	Total fire load
		Mean fire load	Percent of total load				Mean fire load	Percent of total load	"Free" contents	"Adjusted" contents*		
		psf	%	*psf*	*psf*		*psf*	%	*psf*	*psf*	*psf*	*psf*
Office	252	4.9	42.2	1.1	6.0	201	3.5	38.2	2.3	2.4	1.4	4.8
Laboratory	8	7.8	46.8	0.9	8.7	0	------	------	------	------	------	------
Storage	23	20.9	65.4	1.2	22.1	3	4.7	26.4	1.6	2.7	1.5	6.2
Conference	10	2.5	54.7	1.1	3.6	12	2.5	82.9	2.5	2.5	2.2	4.7
Lounge	1	1.3	91.2	1.3	2.6	0	------	------	------	------	------	------
Lobby	7	0.7	51.3	0.3	1.0	1	0.1	4.0	0.1	0.1	1.0	1.1
Dining room	0	------	------	------	------	0	------	------	------	------	------	------
Library	11	15.9	59.3	0.9	16.8	2	7.8	34.4	6.6	7.3	1.0	8.8
File room	3	28.8	63.3	1.0	29.8	2	28.4	58.4	3.3	6.7	0.8	29.2
Other	20	0.4	22.0	0.8	1.2	0	------	------	------	------	------	------
Bldg, Total	335	5.3	45.9	1.0	6.3	221	3.8	40.9	2.3	2.5	1.5	5.3

*According to derating factors in Table 1.

Table 3. *Combustible contents of steel furniture*

Percent combustible contents of room within	NBS Administration Bldg.			FOB 9		
	Offices	File rms.	Total	Offices	File rms.	Total
	(%)	(%)	(%)	(%)	(%)	(%)
Enclosed steel shelving	3.4	2.9	2.6	2.8	0.0	2.6
Steel files and desks	27.3	49.8	23.9	36.7	88.5	40.2
Insulated files, safes	.7	.0	.5	.3	.0	.2

Table 5 gives the percentage of room floor area covered by the occupancy load for each room use category.

Table 6 gives a list of rooms loaded with 25 lb or more per square foot of area. The location and room area is shown along with the value of uniformly distributed load. These are the rooms that are considered to be heavily loaded and are listed for possible reexamination of types and arrangements of loads. As expected these are principally file rooms, storage rooms, and library rooms, although some office rooms are included.

Figures 11 and 12 present frequency distributions (histograms) for uniformly distributed loads in office rooms in the NBS and FOB 9 buildings, respectively. The height of each bar represents the number of rooms

Table 4. *Uniformly distributed load for each floor level in NBS Administration Building and FOB 9*

Equivalent distributed load for each floor level			
Floor	Total Load	Total Area	Dist. Load
FOB 9			
	lb	*ft²*	*psf*
1.0	38184.0	6197.0	6.2
2.0	19565.0	2500.0	7.8
3.0	199413.0	19285.0	10.3
4.0	119478.0	9504.0	12.6
5.0	5440.0	1334.0	4.1
6.0	133531.0	16310.0	8.2
NBS ADMINISTRATION BUILDING			
1.0	65720.0	11178.0	5.9
2.0	55217.0	5859.0	9.4
3.0	88273.0	5947.0	14.8
4.0	80849.0	6037.0	13.4
5.0	61853.0	6040.0	10.2
6.0	110099.0	5900.0	18.7
7.0	89344.0	5989.0	14.9
8.0	94980.0	6283.0	15.1
9.0	76861.0	6059.0	12.7
10.0	57310.0	5996.0	9.6
11.0	43027.0	5532.0	7.8
TOTAL			
17	1339126.0	125950.0	10.6

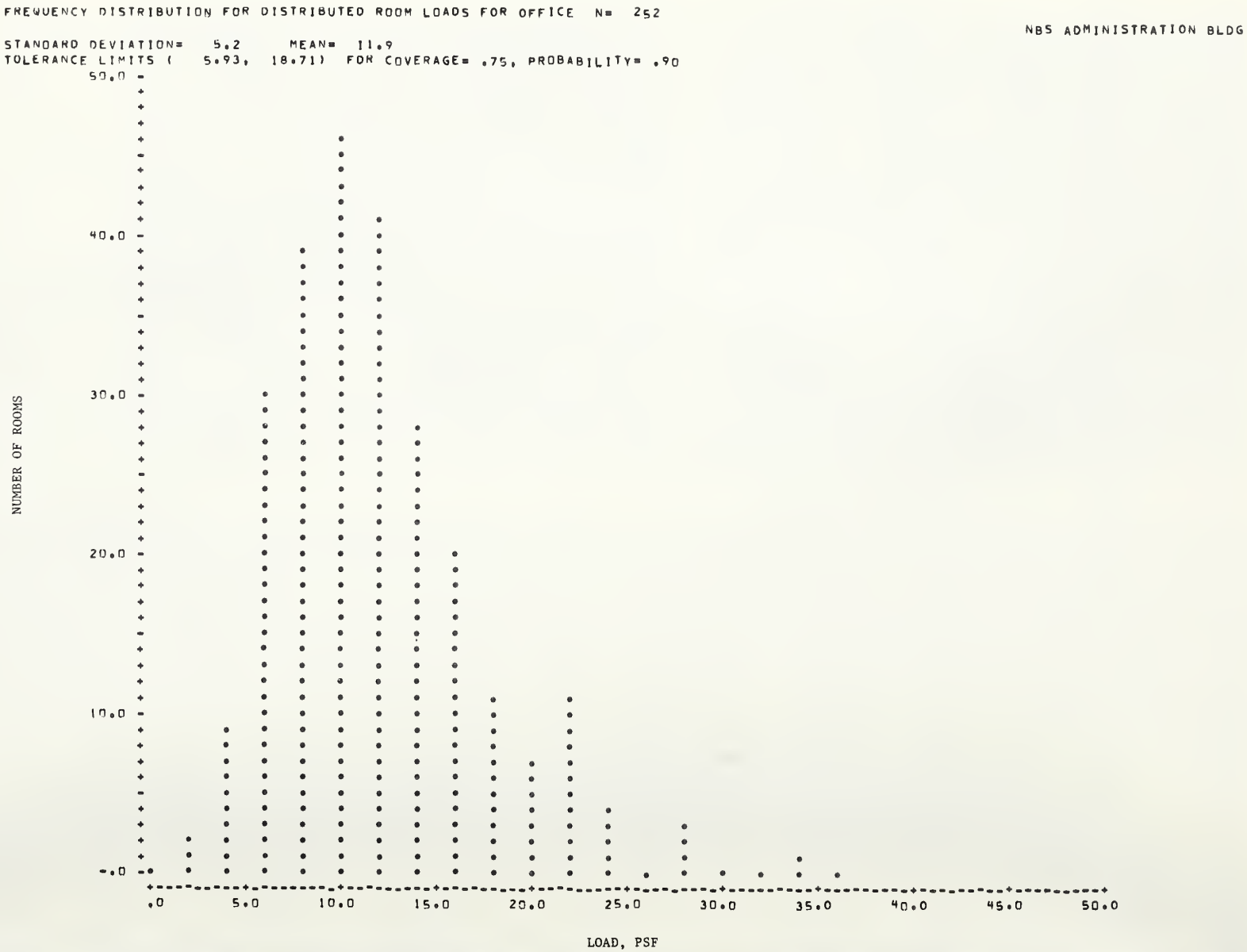


FIGURE 11. *Frequency distribution for uniformly distributed loads in office rooms, National Bureau of Standards Administration Building.*

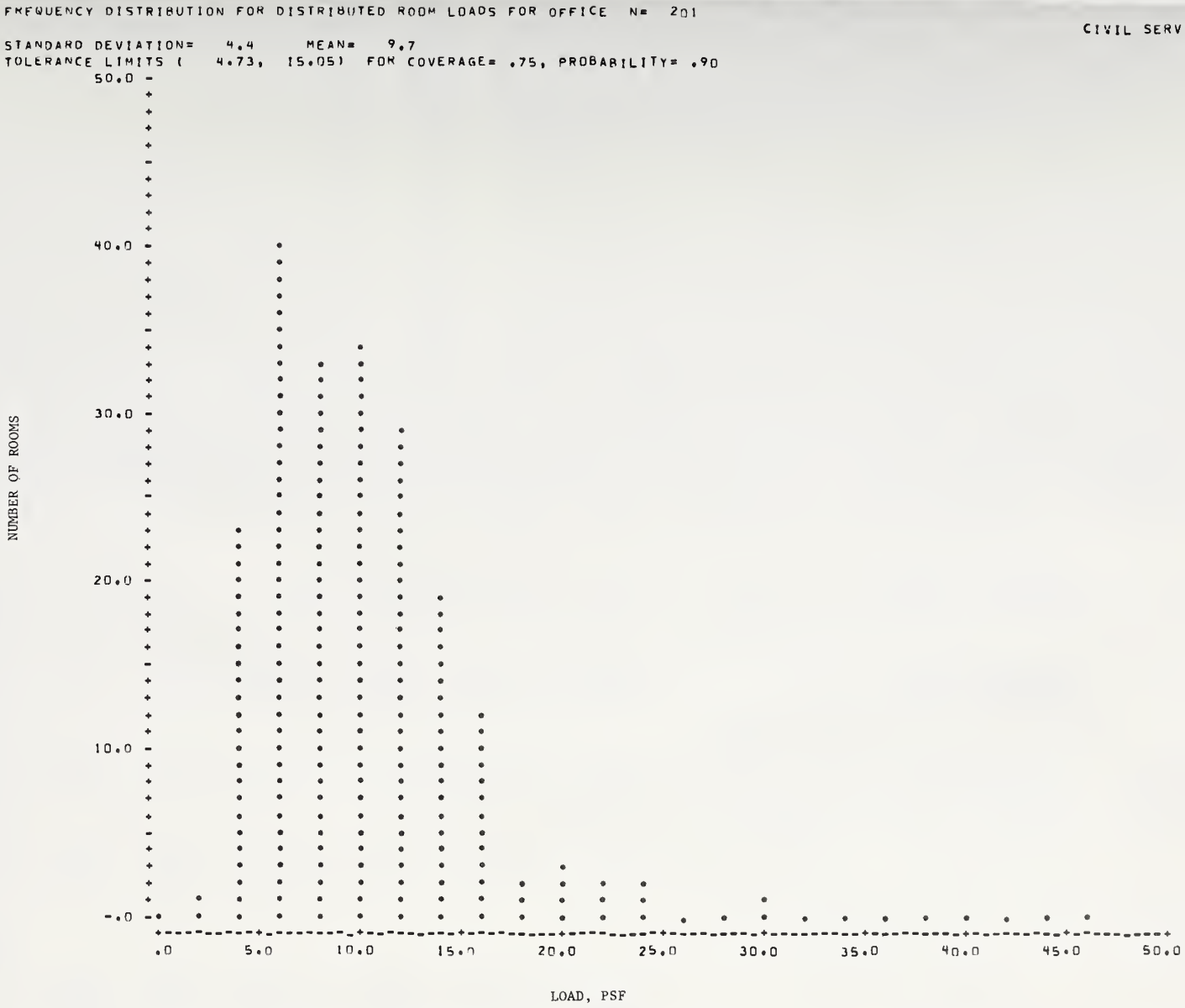


FIGURE 12. *Frequency distribution for uniformly distributed loads in office rooms, Federal Office Building 9.*

Table 5. *Percentage of room floor area covered by the occupancy load for room usage categories and for the building total*

Room use category	Percentage of occupied space	Occupied area	Total area
		ft²	*ft²*
Office	30.7	31363.9	102096.0
Labs	20.9	373.0	1787.0
Storage	26.2	577.3	2200.0
Conference	31.0	2487.8	8022.0
Lounge	15.1	35.9	238.0
Lobby	7.6	311.4	4110.0
Dining Room	.0	.0	.0
Library	31.0	758.7	2444.0
File room	38.3	519.8	1358.0
Other	3.7	135.9	3695.0
Building total	29.0	36563.7	125950.0

Table 6. *Rooms loaded with 25 lb or more per square foot of area*

Room No.	Floor	Distributed load	Room area	Room use
		psf	*ft²*	
03336	3.0	29.4	170.0	1
04445	4.0	57.9	575.0	9
6312A	6.0	29.5	275.0	9
A0123	1.0	59.8	172.0	9
A0303	3.0	30.6	187.0	8
A0335	3.0	46.5	187.0	8
A0404	4.0	38.9	20.0	0
A0422	4.0	28.8	164.0	9
A0424	4.0	34.7	187.0	1
A0439	4.0	26.8	20.0	3
A0442	4.0	42.2	20.0	3
A0629	6.0	48.6	272.0	8
A0631	6.0	63.1	187.0	8
A0633	6.0	52.8	187.0	3
A0635	6.0	47.6	187.0	3
A0700	7.0	27.7	275.0	1
A0719	7.0	46.7	187.0	3
A0730	7.0	25.6	257.0	8
A0835	8.0	30.8	231.0	2
A0839	8.0	34.1	231.0	2
A0840	8.0	27.8	231.0	1
A0900	9.0	28.6	275.0	1
A0922	9.0	46.3	187.0	3
A0924	9.0	31.8	181.0	3
A0928	9.0	47.2	172.0	9
A1102	11.0	32.6	12.0	3
A1106	11.0	72.5	6.0	3
A1118	11.0	44.8	6.0	3
A1135	11.0	58.6	72.0	3

which contain loads within a 2 psf interval extending from 1 psf below to 1 psf above the plotted value. Thus, the bar plotted at zero (0), covers loads up to 1 psf, the bar at 2 psf, includes loads from 1 up to 3 psf, the bar at 4 psf includes loads from 3 up to 5 psf, etc. Note that some statistical data is printed out at the top of the plot.

An important factor in the study of floor loads on buildings may be the relationship between room size and room loads. Figures 13 and 14 show plots of room area versus uniformly distributed load for office rooms in both buildings. More data appears to be necessary in order to delineate a possible relationship between room size and distributed loads.

The load items in office buildings vary widely in weight and in size. The weight of a given item divided by the floor area that it occupies is defined as its discrete unit load. It follows that items of different weight may produce the same discrete load on the floor depending on the respective item size. The sum of the floor areas occupied by load items is defined as the loaded area. Figures 15, 16, 17, and 18 show the relationship between loaded area and discrete load values for office rooms, storage rooms, file rooms, and library rooms in the NBS Administration Building. The area carrying loads greater than a discrete load value is given as a ratio of the total loaded area on the vertical axis and the value of discrete load is given on the horizontal axis. Therefore, these plots indicate the fraction of the loaded area carrying loads greater than a particular value of discrete load. For example, it is seen from figure 15 that 38 percent of the loaded area in office rooms support loads greater than 25 psf.

Figures 19 and 20 show frequency distributions of the percent of room floor area covered by the occupancy load in office rooms in the NBS Administration and FOB 9 buildings, respectively.

Figures 21 and 22 show frequency distributions for movable fire contents in offices in the NBS Administration and FOB 9 buildings, respectively.

Examples of the correlations between weight of combustible contents and estimated amount of contents (percent or cubic feet) are shown for a desk and a file cabinet in figures 23 and 24, respectively. The amount of contents for desks and file cabinets were estimated as percentages of the total storage capacities of the items. For bookcases, volume estimates were made of the amount of contents in units of cubic feet. The weights of combustible contents were determined by subtracting from the total weight recorded for an item, the empty weight of the unit, and the weight of noncombustible content. The plots were constructed to aid in evaluating the work of the survey team members in estimating amounts of contents and to show where improvements or changes in techniques are needed. For each plot a least square fit is given at the bottom of the graph. This is an equation of the straight line most common to all points,

FIGURE 13. *Room area versus distributed load for office rooms (252 rooms), National Bureau of Standards Administration Building.*

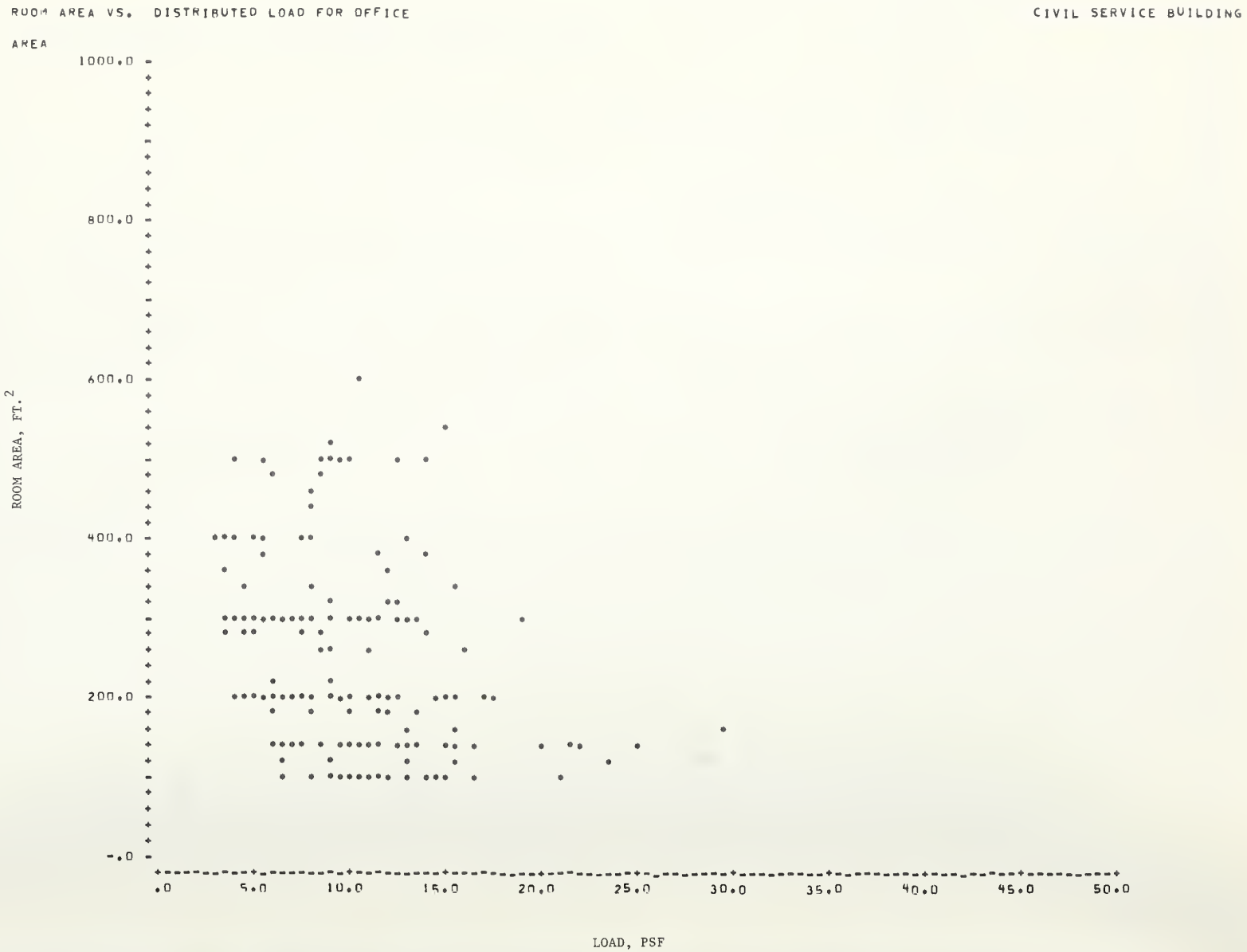


FIGURE 14. *Room area versus distributed load for office rooms (201 rooms), Federal Office Building 9.*

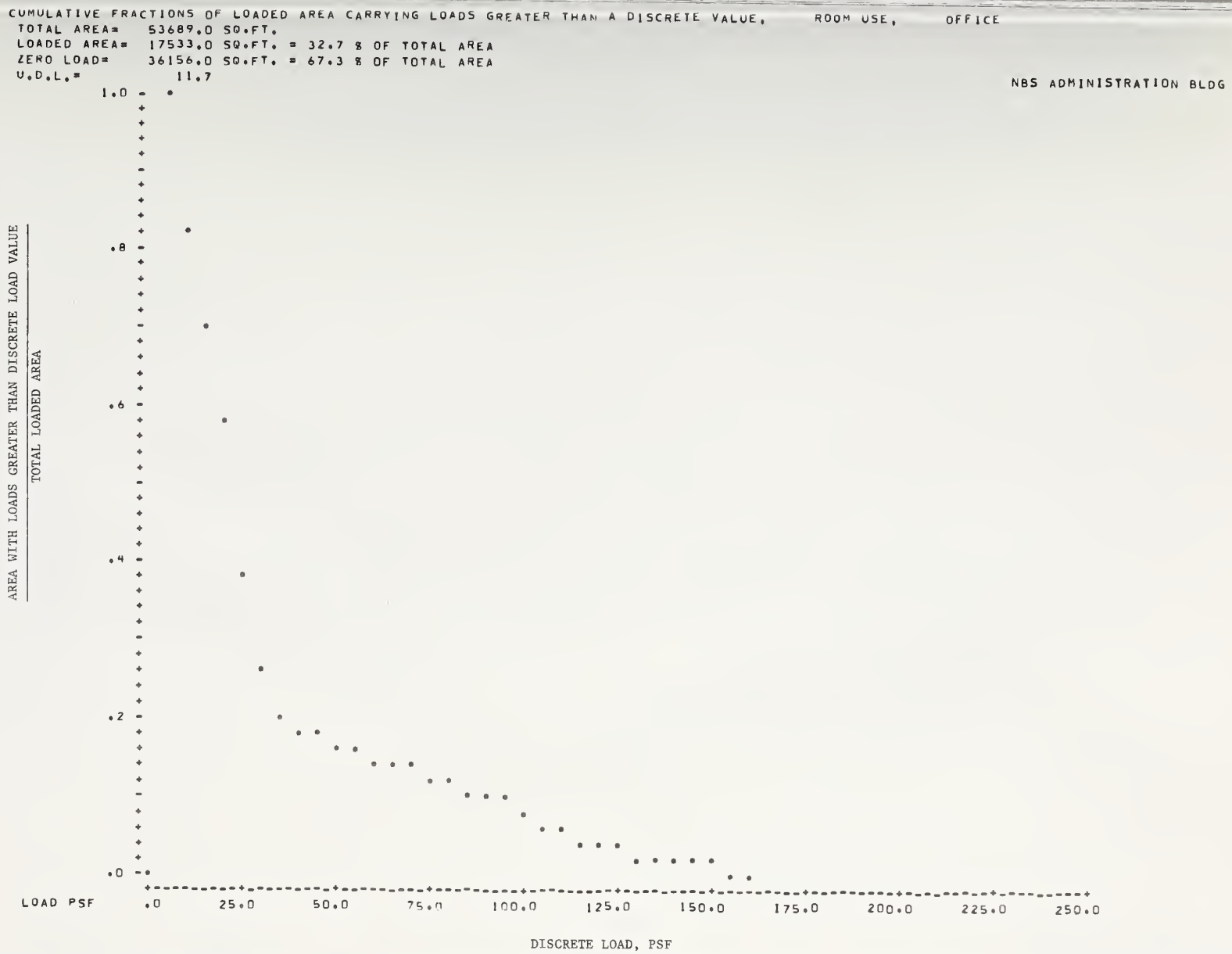


FIGURE 15. *Cumulative fractions of loaded area carrying loads greater than a discrete value for office rooms, National Bureau of Standards Administration Building.*

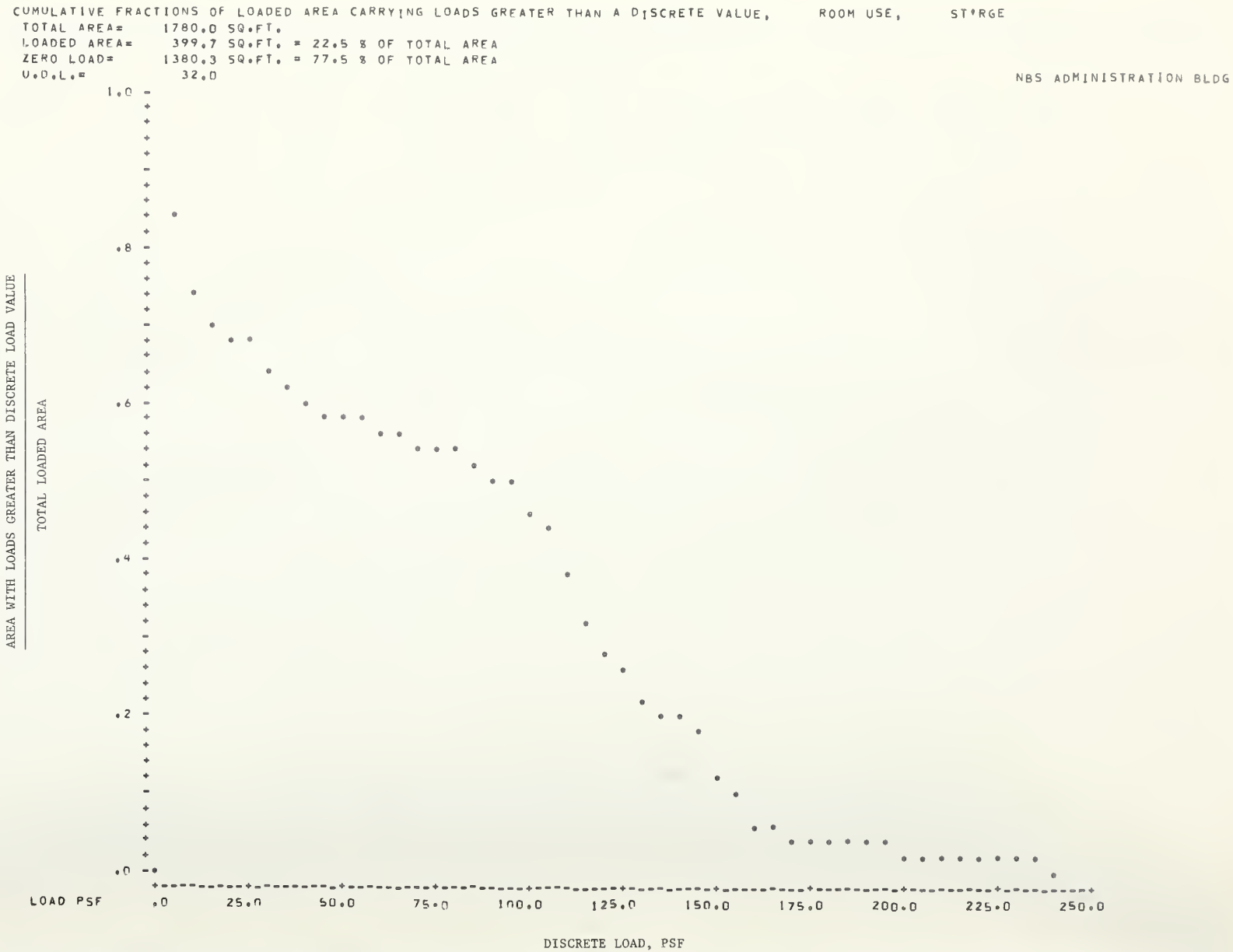


FIGURE 16. *Cumulative fractions of loaded area carrying loads greater than a discrete value for storage rooms, National Bureau of Standards Administration Building.*

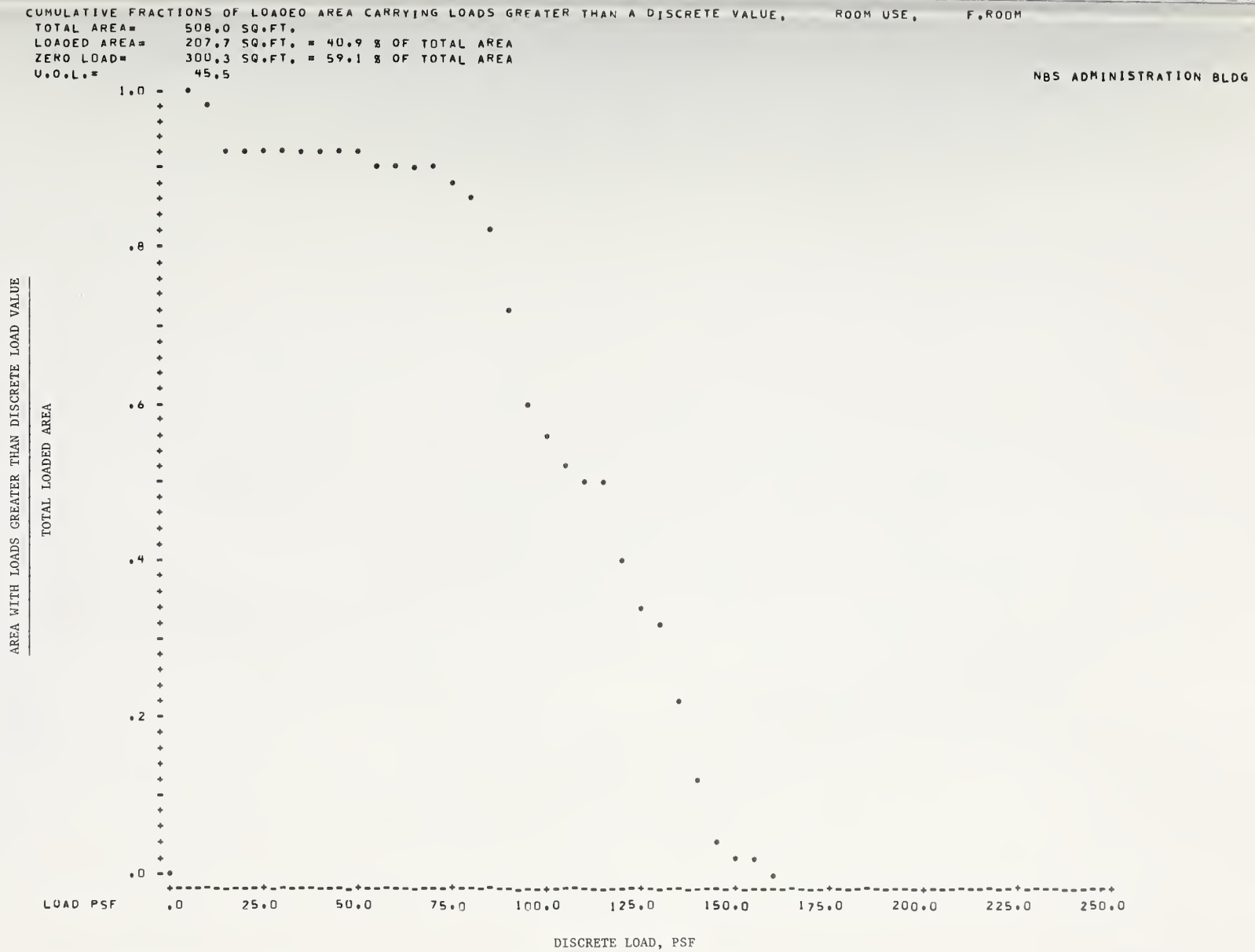


FIGURE 17. *Cumulative fractions of loaded area carrying loads greater than a discrete value for file rooms, National Bureau of Standards Administration Building.*

FIGURE 18. *Cumulative fractions of loaded area carrying loads greater than a discrete value for library rooms, National Bureau of Standards Administration Building.*

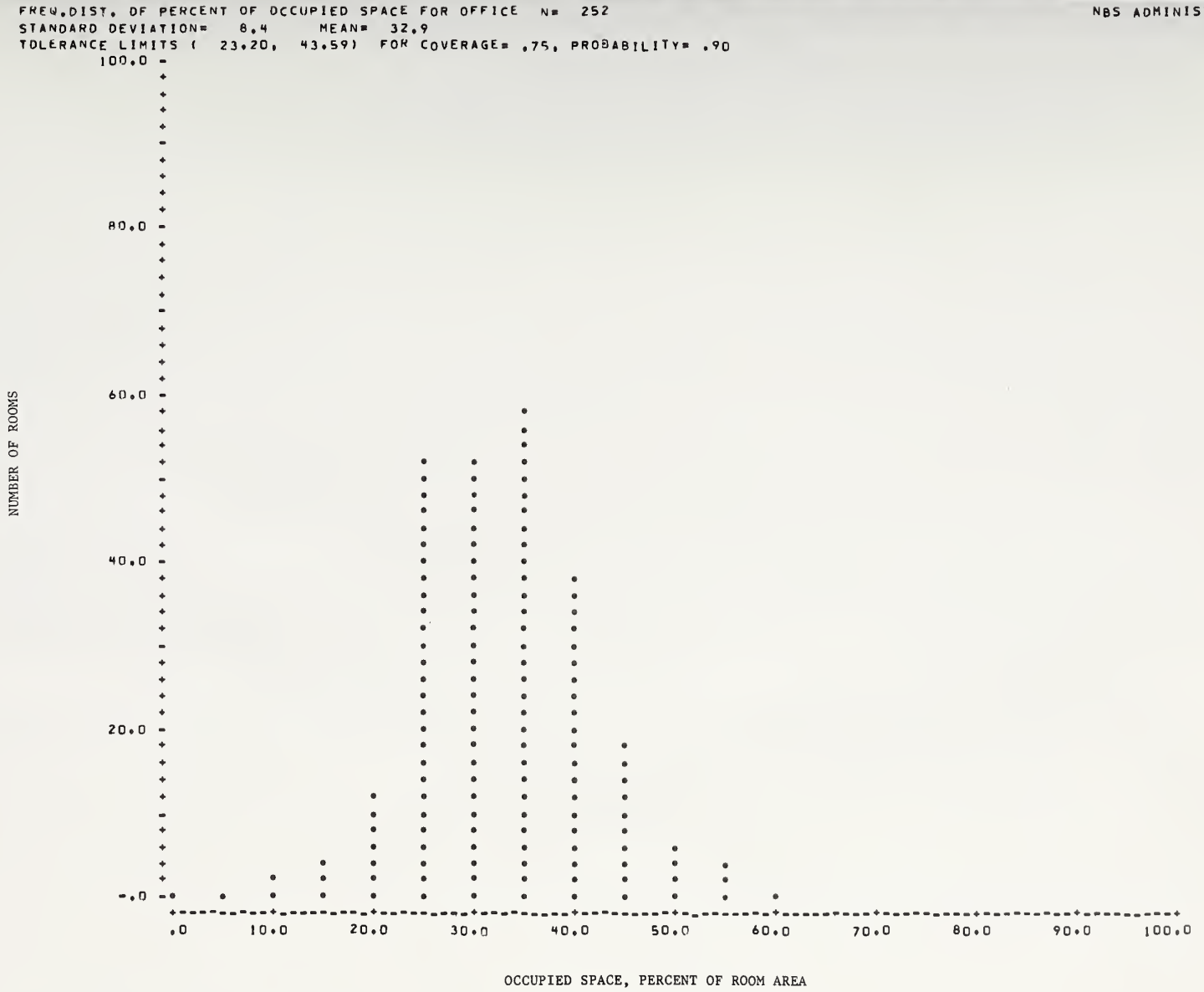


FIGURE 19. *Frequency distribution of the percent of room floor area covered by the occupancy load in office rooms, National Bureau of Standards Administration Building.*

FIGURE 20. *Frequency distribution of the percent of room floor area covered by the occupancy load in office rooms, Federal Office Building 9.*

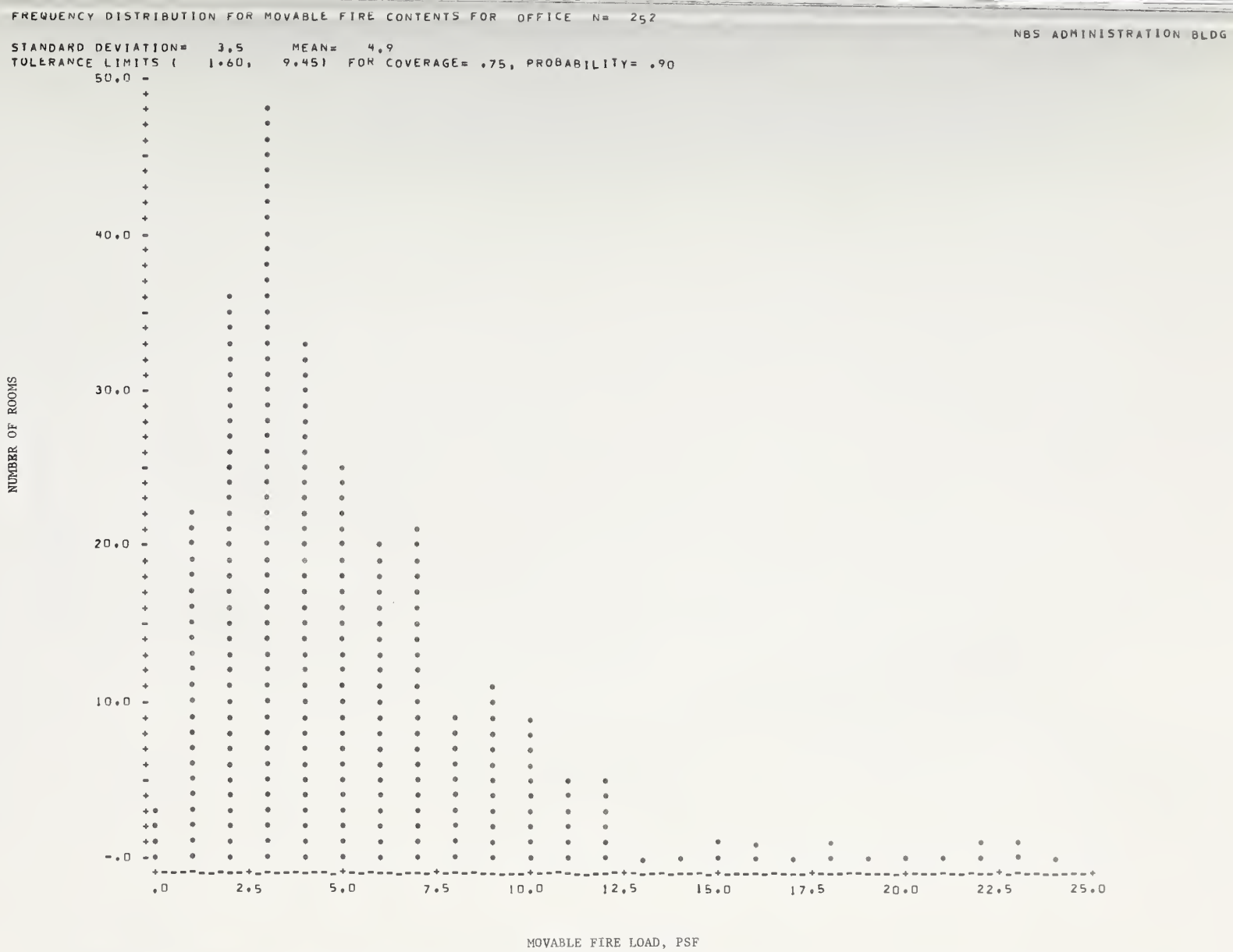


FIGURE 21. *Frequency distribution of movable content fire load in offices, National Bureau of Standards Administration Building.*

FREQUENCY DISTRIBUTION FOR MOVABLE FIRE CONTENTS FOR OFFICE N= 201

CIVIL SERVICE BUILDING

STANDARD DEVIATION= 2.3 MEAN= 3.6
TOLERANCE LIMITS (1.18, 6.49) FOR COVERAGE= .75, PROBABILITY= .90

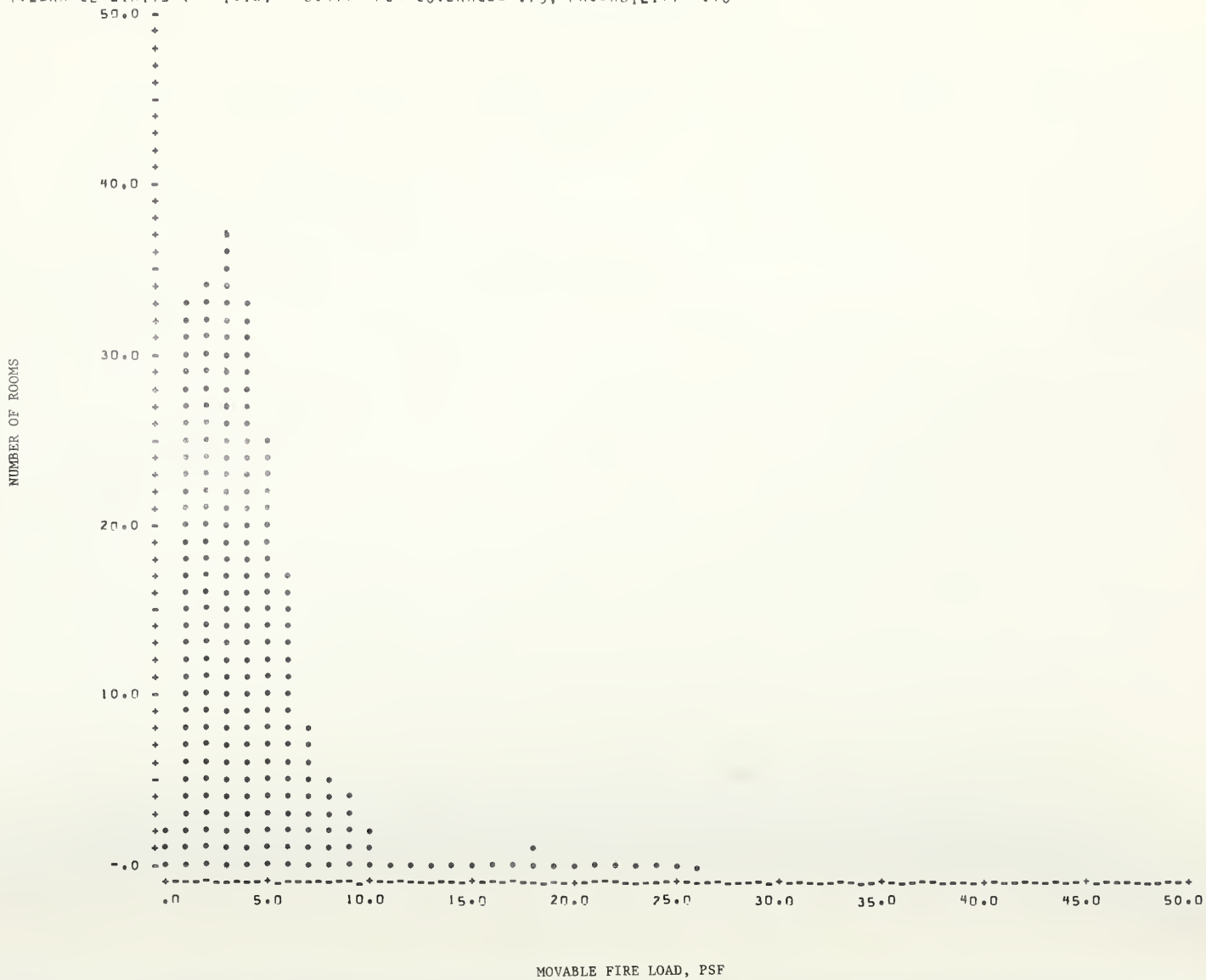


FIGURE 22. *Frequency distribution of movable content fire load in offices, Federal Office Building 9.*

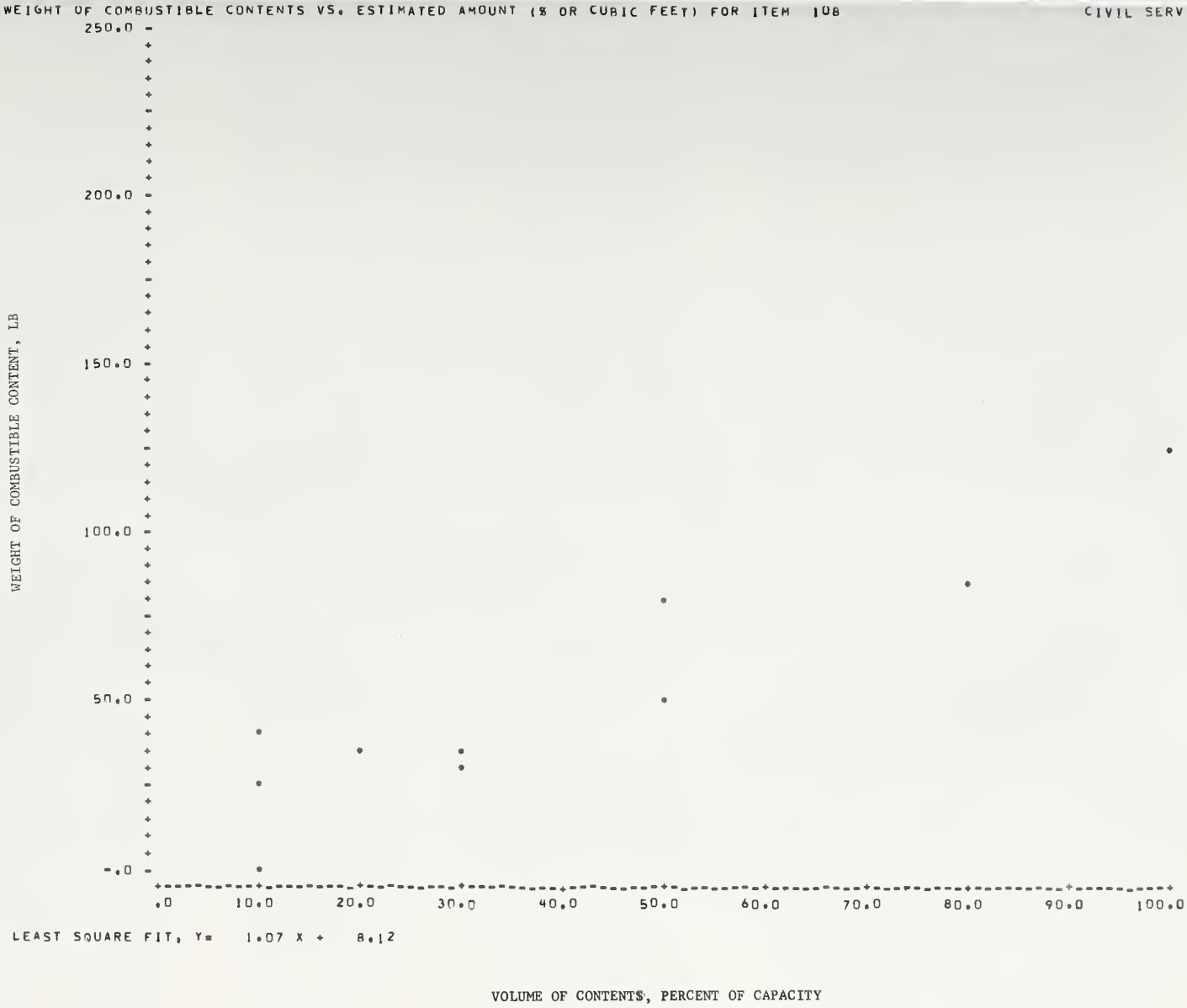


FIGURE 23. *Weight of combustible contents versus estimated amount, desk (code 0108).*

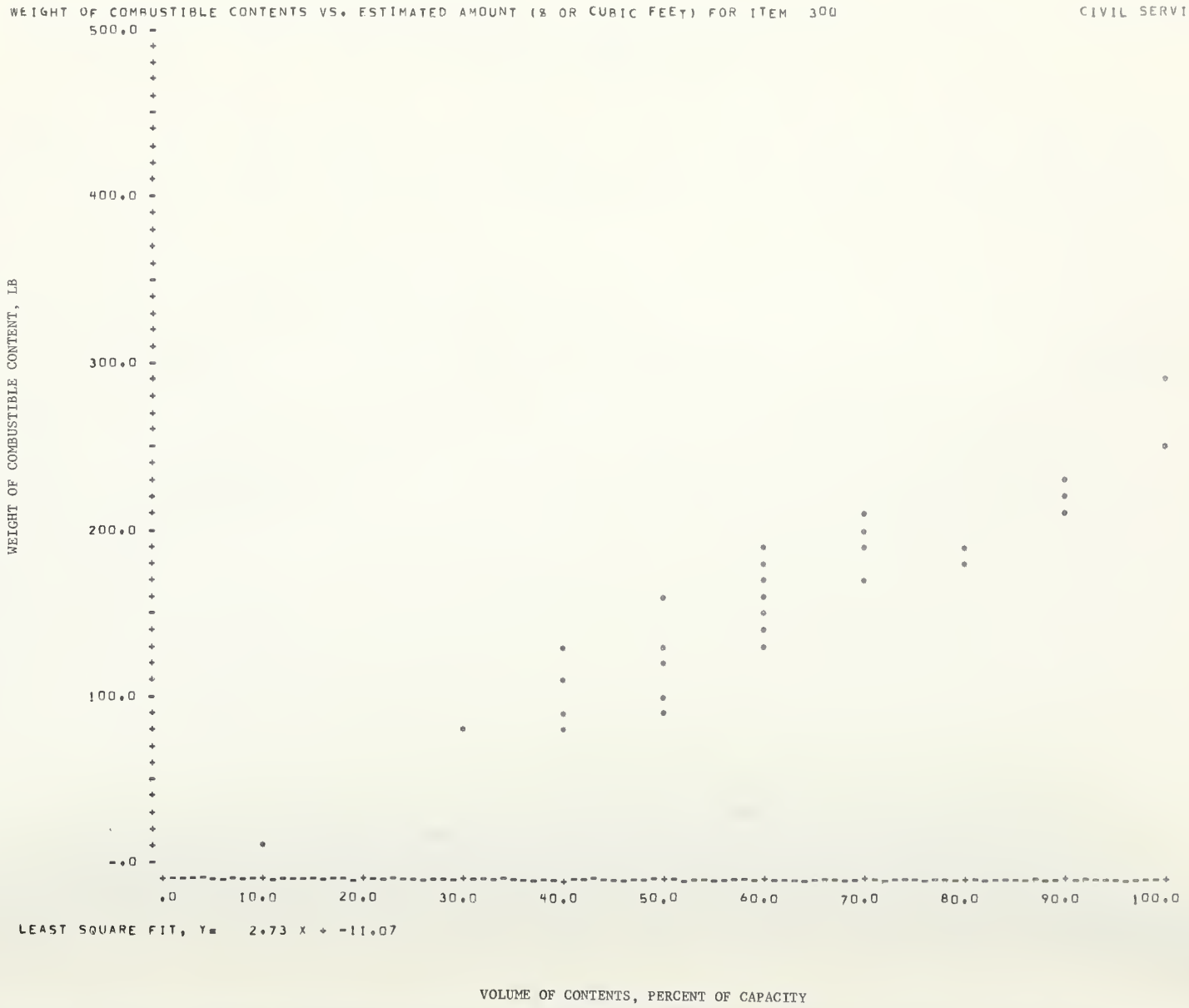


FIGURE 24. *Weight of combustible contents versus estimated amount, file cabinet (code 0300).*

In the case of miscellaneous metal files and of miscellaneous fire-rated files, where the contents measurements were not available * and the empty weights were unknown, the combustible weights were taken as 48 percent and 25 percent of the total weights. These ratios were based on available data from standard files.

6. Discussion

This preliminary survey covered a total of 125,950 ft^2 of which 102,096 ft^2 were considered to be office space. Although this exceeds by over 14,000 ft^2 the office space surveyed and reported in BMS 149, it represents a small statistical sampling from only two buildings, and should not be considered representative of all office space. In particular, the occupancy load is likely to change appreciably over the years.

Compared to the survey results reported in BMS 149, this survey includes a larger sampling (in terms of area), classification of "free" combustible contents (i.e., on top of desks versus within desks) and the spatial distribution of combustible items within the room according to a floor area grid pattern.

6.1. Review of Initial Work

Some changes in survey techniques were made during the course of the work in the pilot study. The most significant ones were concerned with estimating the amount of combustible content associated with items of furniture. Other changes were made to either expedite a measurement procedure or to improve the coordination of the survey team. The net results of these changes were improved efficiency and additional data refinement.

A great deal of attention was devoted to the elimination of human errors in data recording —principally in transferring the data from the log sheets to computer cards. As a result an auxiliary computer program was developed to locate all obvious errors in the data prior to submitting it to the main program.

7. Future Work

Additions to the computer program are planned which will provide statistical comparisons between buildings, and rules for combining or separating data. Also it is planned to use stratified and conditional sampling techniques in future surveys according to the rules of probability sampling. The nature of the work will be evolutionary, depending on past findings to reduce the effort in any structure. One approach is to have the team captain walk through the building before measurements are started assigning each room to a use category and—within large categories like "office"—to a subcategory by weight (heavy, medium, light). The sample of rooms to be surveyed may then be selected using different sampling fractions for different categories and subcategories. All file rooms, storage rooms, etc., will be surveyed until a larger population has been accumulated. The team leader will include in the sample all rooms visually estimated to be in the upper 10 to 15 percent, to permit a finer definition of the extreme loads.

A similar philosophy says office buildings in other geographic regions should be considered to be akin to those already surveyed until a representative sample proves otherwise, whereupon exhaustive surveying would be resumed. This conceptual approach is valid for office building types (government, private, insurance, etc.).

Grateful acknowledgement is made to J. M. Spang for his most valuable contributions to the details of the program in the early stages of the planning and the surveying work; to John Smith, Computer Services Division, for preparing and debugging the computer program, and to all members of the survey team.

8. Selected References

[1] The amount of possible strain on a crowded floor, American Architect and Building News, p. 34, Apr. 15, 1893, Prof. Kernot.

[2] A study of office building live loads, Eng. News Record 90, 584, March 29, 1923.

[3] Minimum live loads allowable for use in design of buildings, Report of the Department of Commerce Building Code Committee, Nov. 1, 1924. (Out of print.)

[4] John W. Dunham, Design live loads in buildings, Trans. Am. Soc. Civil Engrs. 112, 725, 1947.

[5] American standard building code requirements for minimum design loads in buildings and other structures, NBS Miscellaneous Publication M179, 1945.

[6] NBS contributions to building codes, reprint from NBS Tech. News Bull., Oct. 1950.

[7] Live loads on floors in buildings, John W. Dunham, Guttorm N. Brekke, and George N. Thompson, NBS Building Materials and Structures Report BMS133, December 19, 1952.

[8] Fire Resistance Classification of Building Constructions, NBS Building Materials and Structures Report BMS92, 1942.

* In some instances administrative restrictions prevented the survey team from obtaining contents measurements for items containing classified information and for executive's furniture when the individual was not available to give consent.

[9] S. H. Ingberg, J. W. Dunham, and J. P. Thompson, Combustible contents in buildings, NBS Building Materials and Structures Report BMS149, 1957.

[10] J. J. Loftus, D. Gross, and A. F. Robertson, Potential heat—A method for measuring the heat release of materials in building fires, ASTM Proc. 61, 1336-48, 1961.

Appendix A. Description of Coded Records

Data on log sheets

I. First row—general room data—40 digits

(1) Room number—5 digits (alphameric)

(2) Floor level—3 digits; third digit will be zero unless mezzanines, balconies, or the like occur between floors.

(a) Range: −9 to 99, so that basements may be considered.

(b) Examples:

010 = 1st floor
100 = 10th floor
011 = first balcony between 1st and 2d floors
012 = second balcony between 1st and 2d floors
− 010 = 1st basement

(3) Use of room—1 digit

(a) Designates by code the use of the room:

1. Office
2. Laboratory
3. Storage
4. Conference
5. Lounge
6. Lobby, Reception Room
7. Dining Room
8. Library
9. File Room
0. Other

(b) Each type of building will have its own code—i.e., the above code is for an office building.

(4) North-South dimension—3 digits

(a) Floor dimension in feet

(5) East-West dimension—3 digits

(a) Floor dimension in feet

(6) Height of room—2 digits

(a) Measure in feet

(7) Number of male personnel—2 digits

(a) Range: 0 to 99

(8) Number of female personnel—2 digits

(a) Range: 0 to 99

(9) Number of items—2 digits

(a) Total number of items in room

(10) Surface finish—6 digits, to represent, in order, floor, ceiling, North wall, East wall, South wall, West wall.

(a) Designate by code the unit weight expressed in terms of combustible equivalent. Use "Finish Materials List."

0 Noncombustible
1 Less than 0.1 psf
2 0.1 to 0.2
3 0.21 to 0.40
4 .41 to .60
5 .61 to .80
6 .81 to 1.0
7 1.01 to 1.5
8 1.51 to 2.0
9 greater than 2.0 (see notes)

(11) Trim—3 digits

(a) Estimate weight, in pounds, of combustible doors, window sash, shelving, and other trim. Use "Combustible Trim List."

(12) Weight of floor covering—4 digits (whole number, decimal point, and two decimal places)

(a) The unit weight in psf of floor coverings such as carpets, rugs, etc., will be determined and recorded.

(13) Area reduction—4 digits (floating point)

The major N-S and E-W dimensions of a room are used to compute the room area. When there is a recess within the area defined by the major dimensions, the area of this recess is subtracted from the first computed room area.

The recessed area is recorded in square feet under "Area Reduction."

(14) Notes

(a) Unit weight(s) of combustible surface greater than 2.0 recorded in sequence corresponding to order of occurrence of "code = 9" entries from left to right in surface finish columns.

(b) Comments regarding the room in general.

(c) Description of data which are recorded as "other."

II. Second and succeeding rows—28 digits each

(1) Item No.—2 digits

Consecutive numbering of items.

(2) Item code—4 digits

(a) Each item will be assigned a four digit numeric code in accordance with the established coding series.

(b) When an item is encountered that has not yet been assigned a code number and described in reference catalog this column will be left blank, and a description of the item (including empty weight and base area, if possible) will appear under "Notes." Where appropriate, a Polaroid picture will be taken and the log sheet "Item No." written on the back for later reference in assigning an item code.

For unusual or "one-of-a-kind" items, a designation of "miscellaneous" will be written under "Notes."

(3) Location—2 digits (See fig. 1)

(4) Base area code—1 digit

(a) A 1 digit code will be used to indicate whether an item is occupying space on the floor or located on top of another item (e.g., a bookcase section on top of a table)

(b) Code designation—

1—Items occupying space on the floor
0—Items not occupying floor space (the computer will assign the weight of this item to the floor section over which it is located).

(5) Miscellaneous item base area—4 digits

(a) The base area, in square inches, for miscellaneous items only will be recorded in this column.

(b) The base area of items on legs is defined as the area enclosed by straight lines connecting the legs.

(6) Total weight—4 digits

(a) The total weight of the item and its contents in lbs.

(b) Range: 0 to 9999 lbs.

(7) Contents, weight noncombustibles—4 digits

(a) Weight, in pounds, of noncombustible contents, such as metal, glass, etc.

(8) Contents category—1 digit
  (a) Designate by code of content category
    1 100 percent paper
    2 100 percent books
    3 Mixture
(9) Contents measurement
  (a) Percent of capacity—2 digits
    This column records the estimated amount of combustible contents in an item as a percentage of the total capacity of the item for papers. The estimate is recorded to the nearest 10 percent with range from 0 percent to 990 percent (e.g.,, 60 percent is recorded as 06 and 120 percent is recorded as 12)
  (b) Cubic feet—3 digits
    (whole number, decimal point, one decimal place) The amount of contents within selected items are estimated in cubic feet. This estimate is recorded to the nearest tenth of a cubic foot with range from 0.0 ft^3 to 9.9 ft^3.
(10) Combustible contents on top—3 digits
  (whole number, decimal point, one decimal place)
  (a) The amount of free combustible contents on top of certain items (e.g., desks and tables) are associated with those items. The amounts of these contents are estimated in cubic feet to the nearest tenth of a cubic foot with range from 0.0 ft^3 to 9.9 ft^3.
(11) Notes
  (a) Comments regarding the particular item.
  (b) A full description of the item if an item code is not available.
  (c) The weight of contents if the item cannot be weighed while still containing its contents.
  (d) Combustible contents of higher heat of combustion (e.g., plastic, rubber, animal and vegetable oils, fats and waxes, flammable liquids, asphalt, and other petroleum-base products) when present in excess of 20 percent of the total movable contents combustible load for the room.

Appendix B. Computer Program for Live Floor Loads and Fire Loads

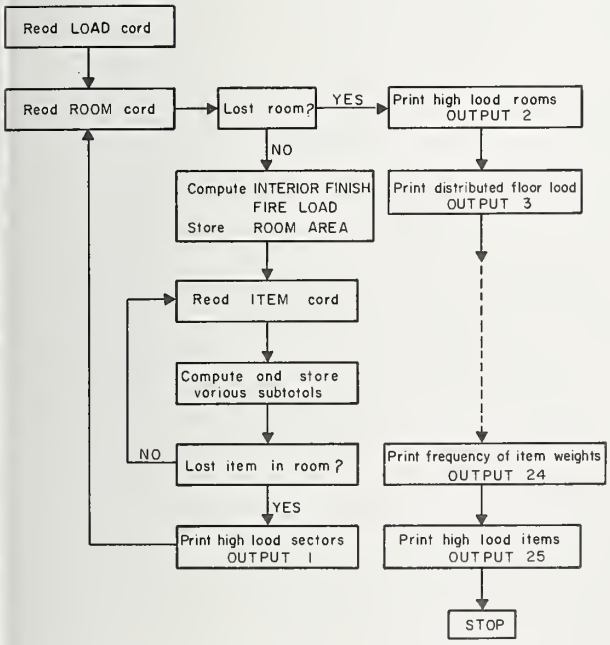


FIGURE B-1. *Computer program block diagram.*

Figure B-1 is a simplified block diagram of the main program. The present output is in the form of 15 tables and 10 sets of graphs, listed in table B-1. A "set" of graphs generally consists of up to 11 individual graphs, one for each of the 10 room use types, and one for the total building. The program consists of a main program, designated LOADS, and five subprograms, designated PLOT, SCALE, SORT 6, STAT, and FREQ. The functions of the subprograms are as follows:

PLOT: This routine is used to plot (a) a series of individual points from given x, y coordinates, or (b) a histogram.

SCALE: This routine is used to calculate the scale of x and y values for the PLOT routine.

SORT 6: This routine arranges blocks of data into ascending order by load concentration. It can handle up to 6000 blocks, each of which consists of five quantities—item code, floor, room number, section, and concentration.

STAT: This routine calculates, for a given set of values, the mean, standard deviation, and tolerance limits.

FREQ: This routine calculates, for a given set of values, the number of occurrences (frequency) within selected intervals of width.

In operation, the program first reads the LOAD card containing values of the limiting weights w_1, w_2, w_3, etc. It then reads the data deck consisting of a ROOM card followed by a prescribed number of ITEM cards. As the cards are read, a series of subtotals are formed, which are indexed according to (a) floor, (b) room, (c) item code, (d) room use code, and (e) room sector. Also, subsets of the room data and item data are written on a drum (the drum could be replaced by a tape for a tape-oriented computer). After the ITEM cards for a given room have been read in, area sectors having a distributed load equal to or greater than w_2 are printed as OUTPUT 1. The process repeats with the next ROOM and associated ITEM cards. A ROOM card with special room number designation ZZZZZ signals the end of the deck, and the program prints OUTPUTS 2 through 21, computed from the appropriate subtotals. Most of these outputs are calculated in disjoint blocks of program so that, with few exceptions, they may be removed from the program if desired, or their order may be changed. To obtain OUTPUTS 22 through 25, the information is read back from the drum in several passes, then selected and organized into the desired form for printout.

TABLE B-1. *Listing of computer program output*

1. Table of room sectors with distributed load greater than or equal to 100 psf.
2. Table of rooms with distributed load greater than or equal to 25 psf.
3. Table of distributed load for each floor.
4. Table of number of items of each type in each type of room.
5. Table of average percent of item capacity.
6. Table of load per item as percent of total load.
7. Plot of relative distribution of loaded area with loads greater than discrete load value.
8. Table of percent of occupied space and total area by room type.

9. Plot of frequency distribution for distributed room loads.
10. Plot of room area versus distributed load.
11. Plot of frequency distribution of percent of occupied space in a room.
12. Table of distribution of interior finish fire loads.
13. Table of mean interior finish fire loads.
14. Table of mean movable fire loads.
15. Table of mean total fire loads.
16. Plot of frequency distribution of movable fire contents.
17. Table of percent of combustible contents within steel desks, files, safes, etc.
18. Plot of frequency distribution of interior finish fire loads.
19. Plot of frequency distribution of total fire loads.
20. Plot of frequency distribution of distributed loads on room sectors.
21. Plot of frequency distribution of surface finish fire load.
22. Plot of combustible contents vs. estimated amount for selected items.
23. Table of frequency of occurrence of items.
24. Table of frequency of item weights.
25. Table of items with distributed load greater than or equal to 150 psf.

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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.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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