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NBS BUILDING SCIENCE SERIES 85

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Survey Results for Fire Loads and Live Loads in Office Buildings

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NBS Building science series, no. 85

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Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

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PREFACE

This report was prepared by the Office of Housing and Building Technology, Center for Building Technology, Institute for Applied Technology, National Bureau of Standards, Washington, D.C. under Subcontract No. BRAB 27-73-53 between the National Academy of Sciences and the National Bureau of Standards. The data on fire loads and live loads presented herein were obtained from a survey of office buildings conducted by the National Bureau of Standards during the period August 1974 through August 1975.

The program of which this work is a part is being sponsored by the Public Buildings Service, General Services Administration, under contract between GSA and the National Academy of Sciences.

ABSTRACT

Fire load and live load data obtained from a survey of 23 office buildings located in various regions throughout the United States are presented. The survey design is described including the characteristics of the building population used to select the sample. Data are presented on the magnitude and distribution of the loads. Information is also included on the characteristics of office loads such as the type of items (furniture, equipment, etc.) and their properties (material type, dimensions, exposure, etc.). Statistical summaries of the data and a determination of the building and occupancy characteristics affecting these loads are presented. The data do not indicate any significant differences between the loads in private and government buildings. Similarly, geographic location, building height, and building age were not found to have a significant influence on load magnitude. The use of the rooms surveyed, however, did affect load magnitude. A mathematical model developed from a regression analysis of the survey data is presented for calculating fire loads and live loads in offices. The data presented may be used to evaluate current requirements for design loads for buildings.

Key words: Buildings; fire loads; load surveys; occupancy live loads; structural engineering.

SI CONVERSION UNITS

In recognition of the position of the U.S.A. as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units in 1960, the author assists readers interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this paper.

Length

1 in = 0.0254* meter
1 ft = 0.3048* meter

Area

1 in^2 = 6.4516* x 10^{-4} $meter^2$
1 ft^2 = 0.09290 $meter^2$

Force

1 lb (lbf) = 4.448 newton

Pressure, Stress

1 psf = 47.88 pascal

Thermal

1 Btu = 1.054 x 10^3 joule

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* Exactly

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1. INTRODUCTION

In order to evaluate the effect of fires on buildings, it is necessary to estimate the potential severity of such fires in addition to the fire resistance of the construction. Tests have shown that there is a definite relationship between the weight of the combustible contents or fire load in a building and the resulting fire severity. The nature of the combustible contents is also important in connection with hazards such as rapid flame spread and smoke generation. Similarly, live load or the weight of all the contents is needed for the structural design of buildings. Requirements for minimum loads for use in design are based on data obtained from load surveys.

Since construction practices evolve over the years and the nature of building contents change, there is a continuing need to update load survey data to reflect current conditions. Recognizing this, the National Commission on Fire Prevention and Control recommended that: "...the fuel (fire) load study sponsored by the General Services Administration and conducted by the National Bureau of Standards be expanded to update the technical study of occupancy fire loads." (1)* Similarly, researchers have pointed out the need for appropriate survey data for use in connection with statistical studies of load variability and the development of probabilistic design approaches (2).

In 1973, the General Services Administration (GSA), the National Academy of Sciences (NAS), and the National Bureau of Standards (NBS) initiated a survey project to determine fire loads and live loads in office buildings. The project represented a continuation of the load survey activities carried out by NBS since 1928 (3,4).

One objective of the project was to identify the building characteristics and occupancy characteristics which affect the magnitude of fire loads and live loads in office buildings and develop mathematical models for predicting future loads. Development of these mathematical models expressing the relationship between the factors and loads would facilitate establishing future minimum design requirements and minimize the necessity for continued load surveys. A second objective was to develop efficient, economic, reliable data collection and data processing procedures applicable to a wide class of buildings of differing occupancy type. This would permit the methodology developed in the project for office buildings to be used for surveys of occupancies such as hospitals, schools, etc.

This report summarizes the survey design, including selection of the survey sample, and describes the type of data collected and the data processing procedure. Data obtained from the survey of 23 office buildings are presented along with results of the analysis identifying the influence of various factors on load magnitude.

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* Figures in parentheses refer to references listed in Chapter 7.

2. SURVEY DESIGN

2.1 General

A complete description of the considerations involved in planning the survey was presented in an earlier report (5) and will, therefore, only be summarized here. The objective of the project was to determine those factors which affect the magnitudes of loads in buildings. Using the survey data, probabilistic models could then be developed to predict loads in buildings based on these factors. Based on results from previous studies and consideration of all the various factors which could affect load magnitude, the factors discussed in Section 2.2 were selected.

It was necessary to limit the number of factors studied in order to obtain a reasonable sample size for the survey. Since considerable judgment was involved in selecting these factors, a two phase effort was planned. The first phase was designed to identify the important factors in the list of all factors initially judged to be potentially significant. The second phase would then concentrate on these important factors. Prior to initiating the first phase, the special survey techniques developed for this project were pretested in a pilot survey involving the NBS Administration Building.

Data obtained from the pilot survey and Phase I are included in this report. Recommendations for additional types of analysis using this data and considerations involved in planning a second phase survey are presented in Chapter 5. The scope of the second phase will be determined at a later date.

2.2 Survey Data

The factors selected for investigation in Phase I which may affect the magnitude of fire and live loads in buildings included:

1. Building location
2. Building height
3. Building age
4. Occupancy characteristics
5. Room use
6. Room size

The type of survey data collected is listed in Figure 1. This included the above factors, information of interest to fire protection engineers in connection with fire severity, and the magnitude and distribution of fire and live loads.

The fire and live loads were limited to those resulting from the intended use of the building. This included furniture, equipment, and other items brought in for the service of the occupants after construction of the building. Data were obtained on the normal number of occupants but no information on their weight was collected or included in computing the loads. Walls and

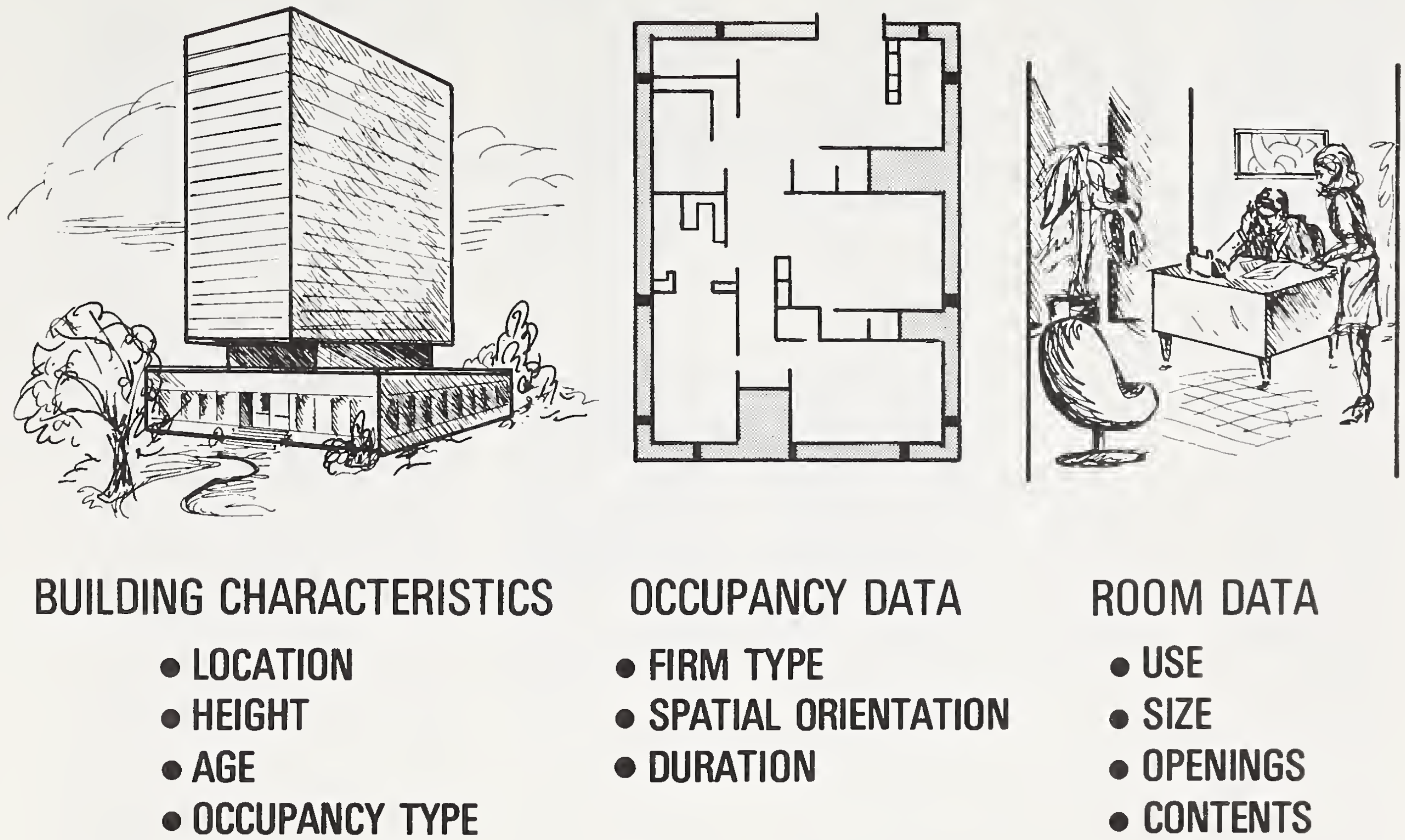


Figure 1 - Type of Survey Data

full height partitions, including removable partitions affixed to the floor and ceiling, doors, and windows were not considered for the case of live load or fire load. Combustible finish materials, including paneling, paint, and wallpaper for walls and full height partitions, ceiling and flooring finish materials and trim such as wooden molding on walls, doors, and windows were included only for fire loads. Loads due to partial height partitions used to subdivide larger areas into work stations were included for both fire and live loads.

The areas within the buildings for which loads were considered were restricted to offices and related work areas. Corridors, lavatories, mechanical equipment facilities, elevators, etc. were not included, however, their locations were recorded. Similarly, basements (i.e. the portion of the building completely below grade) were also not included. Although loads for these areas are important, it was not feasible to include them in the scope of this project.

The pilot survey data were collected over a two-week period of time and the Phase I data over a six-month period and no attempt was made to monitor the change in load with time in a given area. Since the occupancy duration for each area was recorded, however, it was possible to determine the influence of this factor on the load magnitude. Data for the NBS Administration Building could also be compared with data obtained in a survey conducted in 1967 (4). The data also permitted determining the effect of the age of the building on the load magnitude.

Loads were determined for only some of the rooms in the surveyed buildings in order to reduce the field survey effort and still include a large number of buildings. It was assumed that probabilistic models developed from the data could then be used to predict the loads in the unsurveyed rooms. Following this, studies of loads throughout the building could be made. Horizontal and vertical correlations of loads and determination of loads on entire floors, etc. would be possible. Sufficient data were obtained, therefore, to permit extrapolating the results obtained from the surveyed rooms to other areas of similar use within the buildings.

An inventory survey technique employing the collection of data on the physical characteristics of the various room content items was used in this survey. The data collected for each item included: type of item (desk, table, etc.); the construction material (wood, metal, etc.); measured dimensions (length, width, height). For irregular shaped items and irregular piles of paper approximate dimensions were recorded. Weights for each item were then obtained using "average" weights established from manufacturers data for items of similar size and construction. This concept is illustrated in Figure 2 in which the "average" weights are referred to as transfer functions. For small miscellaneous items and equipment, the weight was estimated by the surveyor in lieu of using transfer functions. These transfer functions were presented in an earlier report (5). No direct weighing was used in the survey. This inventory procedure was less time consuming than direct weighing and caused a minimum disruption of the normal business activities in the surveyed rooms. In addition, the inventory procedure provided considerable information on

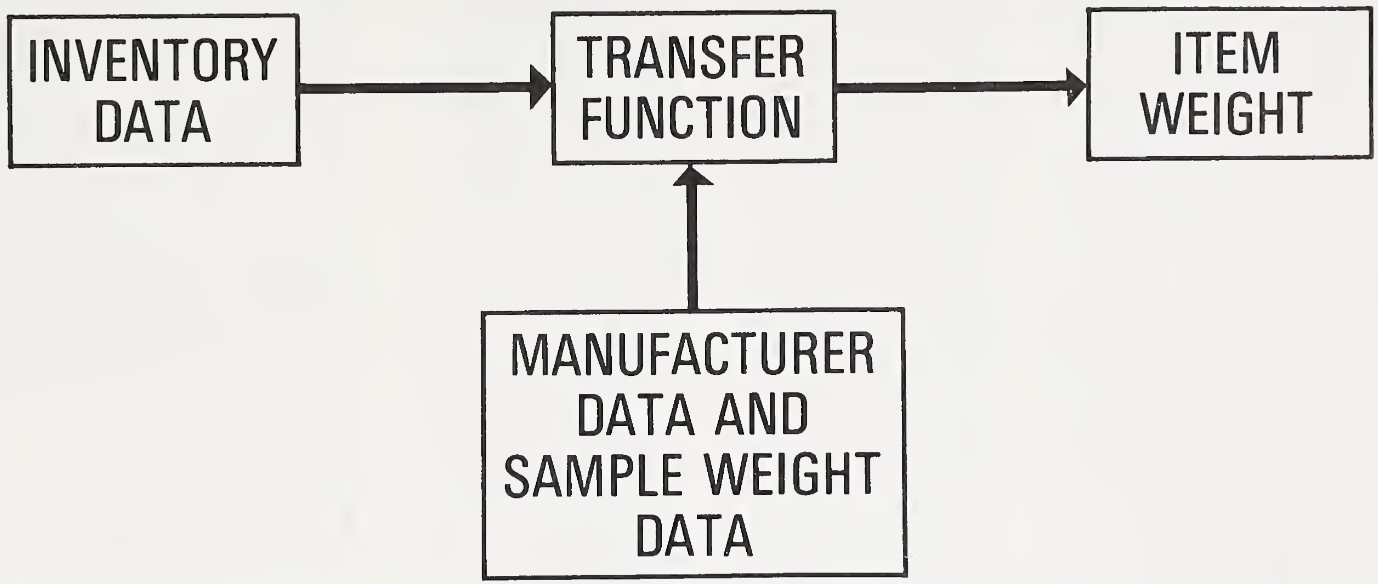


Figure 2 - Inventory Survey Concept

the characteristics of office contents (material type, dimensions, combustibility, etc.) for use in connection with fire related studies. An evaluation of the accuracy for the weight of items obtained using this procedure is given in Section 3.2.

Only the proximity of items in the rooms with respect to the walls and not their exact location was recorded. Studies indicated that this procedure was satisfactory for determining the influence of fire load on structural components (5). Analysis of the influence of this procedure in evaluating live load effects for design of the structural system is included in the Appendix.

2.3 Sampling Plan

The objective of the first phase of the program was to investigate the influence of the building and occupancy factors discussed in Section 2.2 and identify the more important ones. Subdividing the current U.S. office building population into smaller subpopulations grouped according to building height, age, etc., and sampling from each group would permit determining the mean values of the loads for the total population using a weighted sum of the mean loads obtained for each subpopulation. These mean values for each subpopulation could also be used for estimating values for future building populations which are of primary interest for building code purposes simply by changing the weighting factors.

Since a complete inventory of the U.S. office building population listing the characteristics of interest in this study does not exist, available lists were used to select the buildings in the survey. A list of private buildings obtained from the Building Owners and Managers Association (BOMA), an association of independent building owners, and a list of government buildings obtained from the General Services Administration (GSA) were used. In addition to representing different occupancies, private and government, the BOMA and GSA buildings represent two types of occupancy control. Whereas the GSA buildings are completely controlled and involve occupancy by similar tenants, the BOMA buildings are multi-tenant rental buildings with less control over tenant usage of the building.

The height, age, and geographical distribution for these two populations are given in Tables 1 and 2. Originally, twenty private buildings and five government buildings were randomly selected for survey from these lists using the concept of a factorial experiment design (5). Three factors (geographic location, height, age) each having four "levels" were involved. The four census regions for the U.S. were used for geographic location and five story and five year increments were used for height and age. A one-fourth fraction of a 4^3 factorial experiment was used for the private building (7). Characteristics for the buildings selected were presented in an earlier report (5). Unfortunately, considerable difficulty was encountered in securing survey permission for randomly selected private buildings, and only twelve were obtained from the BOMA list. Although specific reasons were not given by those refusing to participate, apprehension concerning disruption of the normal business activities in the offices and the potential use of the survey results may have accounted for their reluctance. Survey permission for additional private buildings was obtained by working through city building

TABLE 1 CHARACTERISTICS OF BOMA OFFICE BUILDING INVENTORY

Height Group (No. of Stories)	Age Group (Years)	Geographic Location*			
		Northeast	Northcentral	South	West
1- 5	1- 5	1	13	26	15
	6-10	1	18	17	9
	11-20	7	14	21	9
	>20	7	22	57	17
6-10	1- 5	1	5	9	8
	6-10	3	8	10	7
	11-20	4	13	15	7
	>20	8	69	54	49
11-20	1- 5	1	6	9	3
	6-10	1	11	14	6
	11-20	5	9	20	9
	>20	21	102	54	41
>20	1- 5	1	14	12	7
	6-10	2	9	7	7
	11-20	2	9	7	8
	>20	17	66	25	9
	TOTALS	82	388	357	211

*Values listed represent number of buildings in each category.

Total number of office buildings available in BOMA inventory - 1,038.

TABLE 2 CHARACTERISTICS OF GSA OFFICE BUILDING INVENTORY

Height Group (No. of Stories)	Age Group (Years)	Geographic Location*			
		Northeast	Northcentral	South	West
1- 5	1- 5 6-10 11-20 >20	0 4 0 62	12 10 12 125	16 25 27 259	7 17 7 122
6-10	1- 5 6-10 11-20 >20	0 3 2 16	5 1 4 11	4 8 10 63	0 8 3 13
11-20	1- 5 6-10 11-20 >20	1 1 1 10	0 2 1 11	1 9 5 8	1 4 0 5
>20	1- 5 6-10 11-20 >20	0 2 0 3	0 3 0 2	0 0 0 1	0 1 0 1
	TOTALS	105	199	436	189

*Values listed represent number of buildings in each category obtained from 1974 GSA RICOS data file.

Total number of office buildings available in GSA inventory - 929.

officials. Due to difficulties in obtaining survey permission, only four additional buildings were obtained giving a total of sixteen private buildings. One additional government building was selected increasing the total number of buildings, including the NBS Administration Building used for the pilot survey, to twenty-three.

The characteristics of the buildings surveyed are given in Table 3 and the geographic distribution is shown in Figure 3. The NBS Administration Building used in the pilot survey is included in the list. The selection procedure for each building is indicated. The random selection refers to buildings randomly selected from the GSA and BOMA lists. In some cases where permission could not be obtained for the first building selected from a given group, a second or third alternate was randomly selected. These are denoted as "Random (2)" or "Random (3)" to indicate that they were not the first building chosen. The buildings not selected from the BOMA list as well as the additional government building from the GSA list are denoted as "Special." The height group, age group, and geographic locations are summarized in Table 4.

The list of buildings presented in Table 3 differs from that included in an earlier report (5). This is due to the difficulties with survey permission noted previously. Some of the buildings in the original sample withdrew their permission. Note that the building numbers in Table 3 are not sequential. It was impractical to reassign sequential numbers to the buildings after a cancellation was received since this would have required adjustments to all the data sheets. Building 27 was added to the original sample to increase the number of rooms surveyed in this phase of the program to the desired level of approximately 2,500. This affected the factorial experiment design as indicated by the data in Table 4 and a one-fourth fraction was not achieved. The effect of this on the analysis of the factors affecting load magnitude is discussed in Section 3.8.

A sampling plan was developed to select the rooms to be surveyed in the buildings (5). The plan was developed to obtain information on the influence of room use, occupancy characteristics, and room size on load magnitude. After classifying all areas in the buildings in accordance with these factors, the rooms in each group were randomly selected and surveyed. Data on these factors for the buildings surveyed are included in Section 3.3. Since the total number of rooms in all the buildings was less than originally estimated, it was possible to increase the fifteen percent sampling rate initially selected (5). Approximately twenty-five percent of the rooms in each building were surveyed except for Buildings 14, 24, and 27. A larger sampling rate was used for these buildings for reasons discussed in Section 3.3.

2.4. Data Collection and Processing

The data collected in the field surveys are described in an earlier report (5). Complete documentation of the computer programs developed for processing these data is also available (6).

The field survey operation involved two visits to each building. During the first visit, information on the characteristics of the building and occupants was collected. Floor plans were used to record data for all areas in the building. This data was then used to select the specific offices to be surveyed in accordance with the established sampling plan. During the second visit, detailed data were collected to obtain the fire loads and live loads for these rooms.

TABLE 3 BUILDING CHARACTERISTICS OF SURVEY SAMPLE

Bldg. No.*	Occupancy Type	Location		Height (No. of Stories)	Age (Years)	Method of Selection ***
		Region	State			
1	Private	North-East	PA	5	13	Random (2)
2	Private	North-East	NY	7	58	Random
3	Private	North-East	PA	21	68	Random
5	Private	North-East	PA	25	23	Random (3)
7	Private	North-Central	IA	5	16	Random
8	Private	North-Central	IL	5	2	Special
9	Private	North-Central	WI	20	10	Random (2)
10	Private	North-Central	IL	23	16	Random
11	Private	South	OK	2	8	Random
12	Private	South	GA	10	73	Special
13	Private	South	GA	10	5	Random (3)
14	Private	South	OK	22	25	Special
17	Private	West	WA	9	11	Random (3)
18	Private	West	AZ	17	13	Random (3)
19	Private	West	WA	49	5	Random
20	Private	West	CA	5	63	Special
21	Government	North-East	PA	3	47	Random
22	Government	North-East	NY	44	7	Random
23	Government	North-Central	IL	2	7	Random
24**	Government	South	MD	12	11	--
25	Government	South	GA	4	6	Random
26	Government	West	CO	2	3	Random
27	Government	West	CA	18	6	Special

*Buildings not numbered sequentially
**NBS Administration Building
***Random - Original random selection from BOMA and GSA lists
Random (2), (3) - Alternate random selection from BOMA and GSA lists
Special - Not randomly selected

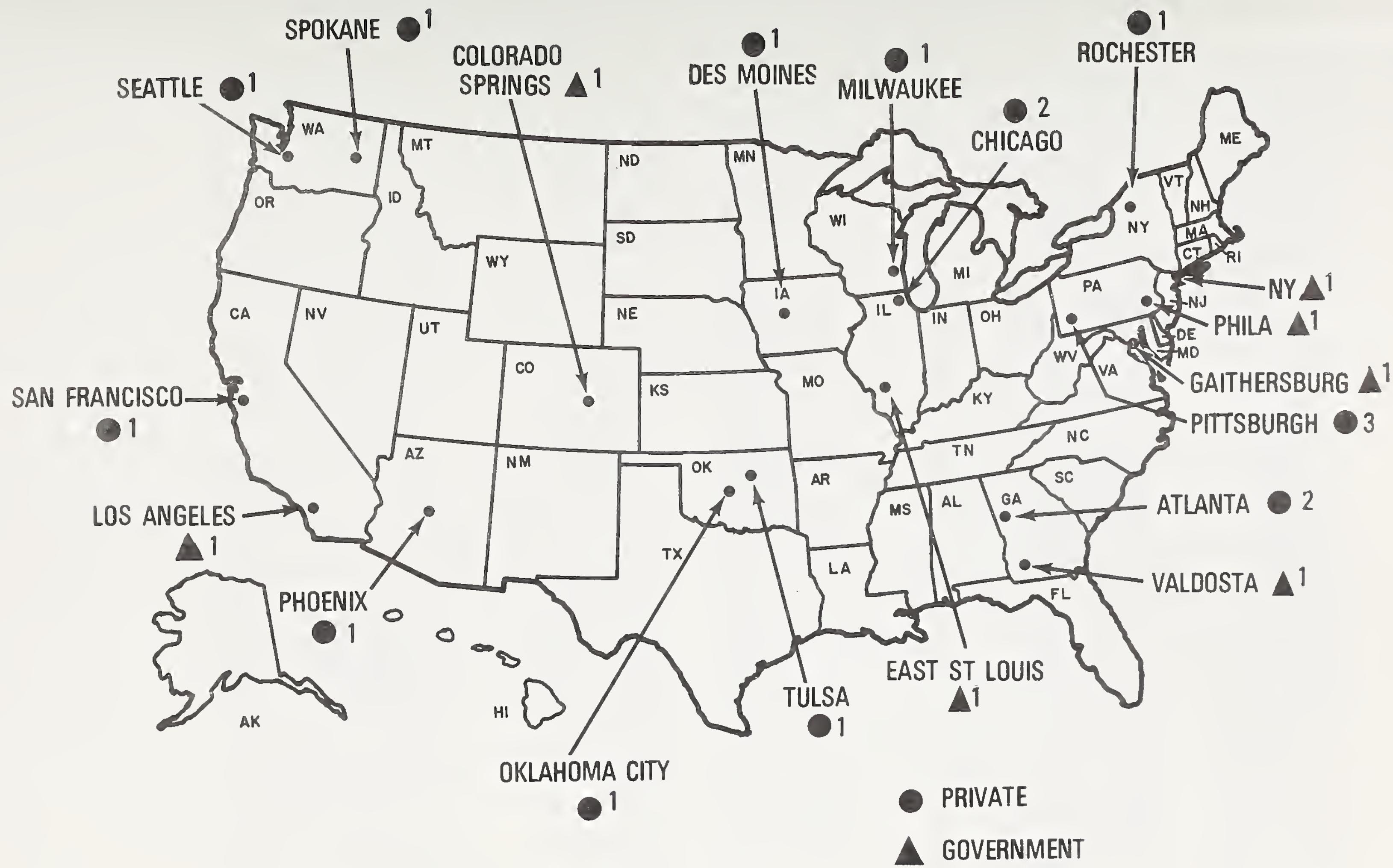


Figure 3 - Geographic Distribution of Survey Sample

TABLE 4 HEIGHT AND AGE GROUPING
FOR BUILDINGS SURVEYED

A. Private Buildings

Height (No. of Stories)	Geographic Location			
	Northeast	Northcentral	South	West
1 - 5	1 (III)	2 (I, III)	1 (II)	1 (IV)
6 - 10	1 (IV)	0	2 (I, IV)	1 (III)
11 - 20	0	1 (II)	0	1 (III)
> 20	2 (IV, IV)	1 (III)	1 (IV)	1 (I)

B. Government Buildings

Height (No. of Stories)	Geographic Location			
	Northeast	Northcentral	South	West
1 - 5	1 (IV)	1 (II)	1 (II)	1 (III)
6 - 10	0	0	0	0
11 - 20	0	0	1*(III)	1 (II)
> 20	1 (II)	0	0	0

* NBS Administration Building

( ) Age Group
I - 1 - 5 years
II - 6 - 10 years
III - 11 - 20 years
IV - > 20 years

The major portion of the data was recorded on specially developed FOSDIC (Film Optical Scanning Device for Input to Computers) data forms. These forms facilitated data collection and expedited the processing effort since they were automatically processed without additional coding or transcription. Microfilming these documents provided a permanent record of the data.

All the survey data were collected by a professional engineering firm working under the general supervision of NBS staff. Technicians with a background in engineering or architecture performed the room surveys under direct supervision of qualified engineers. Each surveyor was provided with detailed instructions for collecting the data (5) and advised of the significance of the survey and the manner in which the data would be used. A short summary version of these instructions was provided for use as a ready reference should questions arise during conduct of the survey. The supervisors provided approximately a ten-hour instruction period for each surveyor to demonstrate the survey procedure and then answered questions arising during conduct of the survey. Minimal supervision and field checking of the data collection forms were required following this initial training. An average time of less than one man-hour was required to survey each room. This was less than half the time required in a previous survey in which the room contents were weighed (4). One man was required for these room surveys as opposed to the four man survey team required to perform the weighing. No special equipment was required and the only disturbance of the occupants of the room involved opening drawers to ascertain the nature and weight of the contents. The only information obtained from the occupants was the number of individuals normally occupying the room.

Special steps were taken to validate and check the data prior to analysis. A one percent validation sample was randomly selected from the total list of rooms surveyed in all the buildings. Following the survey, NBS staff contacted the occupants of these rooms by phone to verify that the survey had been conducted in accordance with the established procedure. In addition, the actual data collected for the room were checked with the occupant to insure that it had been properly recorded. Satisfactory verification was obtained for the survey procedures used and the data collected.

A special purpose computer program was written to check the data. The program was used to detect mechanical errors resulting from automatic processing of the data collection forms and verify that all the required data were collected for each item of furniture, equipment, etc. The program also checked the data against specified tolerance limits to insure that the data were recorded properly, e.g. furniture item dimensions were compared with the dimensions of the room to check compatibility, etc. All data errors detected by the computer were flagged and recorded. Minor errors such as the omission of one piece of information for an item were corrected by the computer program using pre-programmed values (6). When errors occurred in significant data such as room dimensions, all the information for that room was discarded prior to analysis. The errors which occurred were either oversights in which some information for a particular item was not recorded or the dimensions were incorrectly marked on the form. The majority of errors were incorrectly recorded dimensions. There was no apparent trend to these errors, i.e. they did not seem to be related to room use, building height, building age, etc. There were no errors due to misinterpretation of the survey instructions. Of the 2,433 rooms selected, 207 or 8.5 percent were discarded due to errors in significant data.

Initial data processing was done using the digital computer facilities at the National Bureau of Standards and the FOSDIC equipment of the Bureau of the Census. Data reduction and data analysis were performed by the J. H. Wiggins Company under direction and supervision of NBS professional staff. A permanent record of all the original field survey data was retained on microfilm. This information will be available for continuing studies and analyses.

3. DATA ANALYSIS

3.1 General

The analysis included in this report represents only a first step in utilization of the survey data. It is anticipated that the data base obtained in this survey will be used by GSA, NBS, and others in a variety of continuing studies of the loads in buildings. In addition to routine analysis, parameter studies could be carried out, e.g. the impact of changes in office furnishings on fire loads in the buildings surveyed could be determined by modifying the survey data. Such studies will improve our understanding of loads in buildings and facilitate the design of safe economical structures.

The following types of data analysis are included in this chapter:

(1) Evaluation of the inventory survey technique
(2) Determination of the factors affecting load magnitudes
(3) General data analysis
(4) Development and evaluation of mathematical models for predicting loads

Data obtained from the pilot survey of the NBS Administration Building are compared with direct weight measurements in Section 3.2. The characteristics of the survey sample are given in Section 3.3. The influence of building characteristics, occupant characteristics, and room characteristics on load magnitudes is discussed in Sections 3.4, 3.5, and 3.6. General results illustrating the variety of analyses possible using the survey data are included in Section 3.7. Section 3.8 includes results obtained from a regression analysis of the survey data relating load magnitudes and the parameters identified in this survey which affect loads in office buildings. An evaluation of the use of these load models to predict loads in buildings is presented in Section 3.9.

In computing the live loads presented in subsequent sections of this chapter, the weights of furniture, equipment, and their contents were included. The weight of the occupants of the room was not included. The weight of full height partitions was not included. The weight of partial height partitions used to subdivide large areas into work stations was included. Fire loads include the weight of combustible room contents plus the weight of combustible finish materials for walls, ceilings, and floors. In some cases, these two components of the total fire load are presented separately and referred to as "movable contents" (furniture, equipment, etc.) and "interior finish" (walls, ceilings, etc.). The fire loads in this report represent the total weight of combustibles and were obtained by converting the item weights to equivalent weights of combustibles having a calorific value of 8000 Btu/lb. The conversion factors used were presented in a previous report (5). Derated fire loads can be computed from the data. In computing these derated fire loads, the weights for enclosed combustibles such as paper in metal filing cabinets can be adjusted using a derating factor or an estimate of the amount of the material which will burn in a fire (17).

3.2 Evaluation of Inventory Technique

Since the survey technique adopted for this project has not been used previously in a major survey, it was necessary to determine how well the values obtained for the total load in a room compare with those obtained by direct weighing. Room loads obtained using the inventory technique will differ from measured loads for two reasons. First, the numerical values in the transfer functions used to convert the inventory data to weight represent mean values for the item groups. Thus, unless the weight of each item in a given room equals the mean weight for that item group, the weights will differ. Second, the survey technique requires some estimation on the part of the surveyor, e.g. weight estimation for miscellaneous items and approximation of "average" sizes and the height of irregular piles for paper and books for use in the transfer functions. These same kinds of approximations occurred in the Bryson and Gross (4) and Mitchell (8) surveys. Although they obtained "exact" values for the total load in a room, the weight of the contents of drawers, etc. were estimated. Whereas, the approximations in this survey affect both the fire load and live load, approximations in the surveys involving direct weighing affect only fire loads.

The NBS Administration Building was selected to evaluate the inventory technique. This building was chosen for convenience and also because weighing operations could be scheduled to provide minimum disruption of the normal business activities. One hundred and fifty-nine rooms were surveyed in the building. Fourteen of these rooms were randomly selected and, following the inventory survey, a follow-up survey involving weighing of all the room contents was conducted. These 14 rooms were either general or clerical offices. These same rooms were also resurveyed several times by different surveyors using the inventory technique to establish the variability between surveyors. The weighing was conducted immediately following the inventory survey to insure that the room contents were the same for both surveys. This weighing was done with the same equipment used in the survey of the building carried out in 1967 (4).

A comparison of results obtained for the two surveys is given in Table 5. The floor number and room number given correspond to the identification scheme used in conducting the survey. The numbers in parentheses correspond to the room numbers assigned by the tenant. For the 14 rooms, there are 50 inventory surveys by seven surveyors. Each room was surveyed at least three times by three different surveyors. The total weight obtained from the weighing survey and inventory weights obtained by the various surveyors are given for each room. The percent difference between these values and between the measured weight and the mean of the weight obtained by the surveyors for a given room are also given. Note that the inventory weights for the various surveyors in any one room are not exactly the same. Also for Room 527 (Floor 6, Room 24), Surveyor 002 surveyed this room twice and obtained two slightly different values. Before comparing the measured and inventory weights, it is of interest to look at the reasons for these differences.

TABLE 5 COMPARISON OF INVENTORY WEIGHTS AND MEASURED WEIGHTS

NBS Administration Building

Room No.	Area (ft^2)	Measured Weight (lb) (1)	Surveyor	Total Inventory Weight (lb) (2)	Percent Difference $\left[\frac{(1)-(2)}{(1)}\right] \times 100$	Mean Inventory Weight (lb) (3)	Std. Dev. of Inventory Weights (lb) (4)	Percent Difference $\left[\frac{(1)-(3)}{(1)}\right] \times 100$
Floor 3 Room 10 (224)	180	1508	001 002 005	1353 1385 1781	10 8 -18	1506	238	0.13
Floor 3 Room 12 (228)	180	2148	001 002 005	2075 2162 2312	3 - 1 - 8	2183	120	- 1.63
Floor 3 Room 24 (231)	180	1953	001 002 005	1923 1924 1898	2 1 3	1915	14.7	1.95
Floor 3 Room 20 (239)	177	3774	001 004 005	3574 3859 3782	5 - 2 0	3738	147	0.95
Floor 4 Room 37 (305)	180	2083	001 002 006	2503 2623 2625	-20 -26 -26	2584	70	-24.04
Floor 4 Room 33 (313)	180	2645	001 002 005	2508 2539 2518	5 4 5	2522	15.8	4.65
Floor 4 Room 29 (321)	178	3840	001 002 005	3950 3846 3388	- 3 0 12	3728	299	2.92

TABLE 5 (Continued)

Room No.	Area (ft^2)	Measured Weight (lb) (1)	Surveyor	Total Inventory Weight (lb) (2)	Percent Difference $\left[\frac{(1)-(2)}{(1)}\right] \times 100$	Mean Inventory Weight (lb) (3)	Std. Dev. of Inventory Weights (lb) (4)	Percent Difference $\left[\frac{(1)-(3)}{(1)}\right] \times 100$
Floor 5 Room 30 (419)	177	3129	000 001 004 005	3292 3632 2778 2821	- 5 -16 11 10	3131	407	- 0.06
Floor 5 Room 10 (422)	163	3031	000 001 002 004	2612 3190 2544 3391	14 - 5 16 -12	2934	420	- 3.19
Floor 5 Room 28 (423)	177	1583	000 001 002 004	1765 2010 2015 2112	-12 -27 -27 -33	1975	148	-24.79
Floor 6 Room 26 (523)	174	3597	000 001 002 003 004	3638 4000 3763 3751 3767	- 1 -11 - 5 - 4 - 5	3784	132	- 5.19
Floor 6 Room 11 (526)	265	1271	001 002 003 004	1628 1549 1679 1604	-28 -22 -32 -26	1615	54	-27.06

TABLE 5 (Continued)

Room No.	Area (ft^2)	Measured Weight (lb) (1)	Surveyor	Total Inventory Weight (lb) (2)	Percent Difference $\left[\frac{(1)-(2)}{(1)}\right] \times 100$	Mean Inventory Weight (lb) (3)	Std. Dev. of Inventory Weights (lb) (4)	Percent Difference $\left[\frac{(1)-(3)}{(1)}\right] \times 100$
Floor 6 Room 24 (527)	174	2203	001 002 002 004	2312 2055 2152 2307	- 5 7 2 - 5	2207	125	- 0.18
Floor 7 Room 13 (634)	176	3354	001 002 005 006	3435 3529 2922 3469	- 2 - 5 13 - 3	3339	281	0.45

TABLE 6 INVENTORY DATA FOR RANDOM SAMPLE OF ROOMS

Room No.	Area (ft^2)	Surveyor	Total Inventory Wt. (lb) (1)	Std. Dev. (lb) (2)	Est. Wt. (lb) (3)	Wt. Paper and Books (lb) (4)	Transfer Function Wt. (lb) (1)-(3)-(4)	$\frac{\text{Est. Wt.}}{\text{Total Wt.}} \times 100$ $\left[(3)/(1)\right] \times 100$	$\frac{\text{Wt. Paper, Books}}{\text{Total Wt.}} \times 100$ $\left[(4)/(1)\right] \times 100$	No. Items
Floor 3 Room 10 (224)	180	001	1353	74	27	321	1005	2.0	23.7	16
		002	1385	85	47	241	1097	3.4	17.4	16
		005	1781	181	49	378	1354	2.8	21.2	14
Floor 3 Room 12 (228)	180	001	2075	99	18	554	1503	0.9	26.7	18
		002	2162	89	33	822	1307	1.5	38.0	19
		005	2312	191	47	570	1695	2.0	24.7	18
Floor 3 Room 24 (231)	180	001	1923	68	43	428	1452	2.2	22.3	18
		002	1924	82	19	374	1531	1.0	19.4	17
		005	1898	68	61	415	1422	3.2	21.9	17
Floor 3 Room 20 (239)	177	001	3574	109	79	1273	2222	2.2	35.6	29
		004	3859	119	91	1393	2375	2.4	36.1	22
		005	3782	114	70	1326	2386	1.9	35.1	22
Floor 4 Room 37 (305)	180	001	2503	93	103	501	1899	4.1	20.0	24
		002	2623	106	141	470	2012	5.4	17.9	24
		006	2625	117	74	336	2215	2.8	12.8	23
Floor 4 Room 33 (313)	180	001	2508	103	130	861	1517	5.2	34.3	26
		002	2539	92	68	856	1615	2.7	33.7	26
		005	2518	104	139	790	1589	5.5	31.4	17
Floor 4 Room 29 (321)	178	001	3950	99	110	2506	1334	2.8	63.4	32
		002	3846	91	92	2616	1138	2.4	68.0	43
		005	3388	97	121	1934	1333	3.6	57.1	20

TABLE 6 (Continued)

Room No.	Area (ft^2)	Surveyor	Total Inventory Wt. (lb) (1)	Std. Dev. (lb) (2)	Est. Wt. (lb) (3)	Wt. Paper and Books (lb) (4)	Transfer Function Wt. (lb) (1)-(3)-(4)	$\frac{\text{Est. Wt.}}{\text{Total Wt.}} \times 100$ $\left[(3)/(1)\right] \times 100$	$\frac{\text{Wt. Paper, Books}}{\text{Total Wt.}} \times 100$ $\left[(4)/(1)\right] \times 100$	No. Items
Floor 5 Room 30 (419)	177	000	3292	100	147	1087	2058	4.5	33.0	18
		001	3632	127	87	993	2552	2.4	27.3	19
		004	2778	84	283	829	1666	10.2	29.8	17
		005	2821	89	168	779	1874	6.0	27.6	17
Floor 5 Room 10 (422)	163	000	2612	102	67	1247	1298	2.6	47.7	17
		001	3190	105	195	1513	1482	6.1	47.4	24
		002	2544	102	132	1326	1086	5.2	52.1	24
		004	3391	104	78	1819	1494	2.3	53.6	17
Floor 5 Room 28 (423)	177	000	1765	109	38	584	1143	2.2	33.1	13
		001	2010	100	115	679	1216	5.7	33.8	18
		002	2015	100	127	666	1222	6.3	33.1	18
		004	2112	95	6	665	1441	0.3	31.5	13
Floor 6 Room 26 (523)	174	000	3638	96	59	1094	2485	1.6	30.1	18
		001	4000	118	140	1038	2822	3.5	26.0	23
		002	3763	113	142	964	2657	3.8	25.6	22
		003	3751	105	77	1103	2571	2.1	29.4	22
		004	3767	115	149	948	2670	4.0	25.2	23
Floor 6 Room 11 (526)	265	001	1628	74	85	253	1290	5.2	15.5	21
		002	1549	76	32	233	1284	2.1	15.0	21
		003	1679	111	78	182	1419	4.7	10.8	21
		004	1604	76	52	263	1289	3.2	16.4	22

TABLE 6 (Continued)

Room No.	Area (ft^2)	Surveyor	Total Inventory Wt. (lb) (1)	Std. Dev. (lb) (2)	Est. Wt. (lb) (3)	Wt. Paper and Books (lb) (4)	Transfer Function Wt. (lb) (1)-(3)-(4)	$\frac{\text{Est. Wt.}}{\text{Total Wt.}} \times 100$ $\left[(3)/(1)\right] \times 100$	$\frac{\text{Wt. Paper, Books}}{\text{Total Wt.}} \times 100$ $\left[(4)/(1)\right] \times 100$	No. Items
Floor 6 Room 24 (527)	174	001	2312	80	43	880	1389	1.9	38.1	27
		002	2055	71	19	748	1288	0.9	36.4	16
		002	2152	79	50	871	1231	2.3	40.5	27
		004	2307	78	57	1001	1249	2.5	43.4	18
Floor 7 Room 13 (634)	176	001	3435	77	350	1203	1882	10.2	35.0	37
		002	3529	79	316	1207	2006	9.0	34.2	45
		005	2922	76	317	894	1711	10.9	30.6	16
		006	3469	78	218	1226	2025	6.3	35.3	50

A detailed breakdown of the inventory weight data is given in Table 6. The contribution to the total inventory weight is given for: the furniture and equipment (obtained from the transfer functions); the weight of paper and books (also obtained from transfer functions); and the weight of miscellaneous items which were estimated by the surveyors. The standard deviation for the total inventory weight obtained by combining the standard deviations associated with the transfer functions for each item of furniture and equipment (5) is also given.

The estimated weights for the various surveyors in a given room vary considerably. In some cases the differences were greater than 100 percent. This is to be expected since the surveyors were not given any special training in estimating weights. The contribution of these estimated weights to the total weight in the room, however, is very small; in most cases, five percent or less. Extensive training of the surveyors in estimating item weights would, therefore, not significantly improve the accuracy of the survey technique.

The weight of paper and books in these offices contributed substantially to the total weight. This contribution ranged from approximately twenty percent to as high as sixty-eight percent. Since it was necessary to select average sizes for a given pile of paper or books and the height of disorganized piles or stacks had to be estimated, the surveyors obtained different weights. As noted previously, estimation errors of this type also occur in surveys using direct weighing unless the furniture items and contents are weighed separately.

Differences also occurred in the various surveyor weights from the transfer functions. Although the item groups used in the transfer functions are not extremely sensitive to the measured dimensions of the item, differences did occur. For example, in Room 527, Surveyor 002 obtained slightly different values of weight from the transfer functions for the two times he surveyed the room. In addition, errors occurred in correctly identifying a particular furniture item or in recording the data and account for the variation among surveyors.

These results are understandable and do not indicate any serious difficulties with the inventory survey technique. Referring to Table 5, the percent difference between the inventory weights and measured weights is reasonable in most cases. For three of the rooms (Rooms 305, 423, 526), however, the percent difference was large. A detailed review of these rooms indicated that they were similar to the other rooms surveyed with respect to the type of contents. It was also not possible to attribute these differences to the survey procedure (time of day, day of the week, etc.). Studies of the data indicated that the differences were due to surveyor error. Data for Room 423 in Table 7 illustrate this. Note that the total inventory weight for each surveyor consists of the sum of the item weights, the content weight, and the weight of the miscellaneous items in Table 7. In some cases measurement errors occurred, in others errors in identification of furniture items occurred or data were not recorded.

In order to minimize the chances of including erroneous survey data in the results, data from the twenty-three buildings were checked prior to analysis. Obviously, detailed checking similar to that discussed was not feasible. Certain logic type checks were made, however, during the data processing and some data discarded.

TABLE 7 DETAILED ANALYSIS OF INVENTORY DATA
(Floor 5, Room 28)

Item No.	Item Description	Meas. Wt* (lb)	Surveyor No. 000				Surveyor No. 001				Surveyor No. 002				Surveyor No. 004			
			Tot. Wt (lb)	Cont. Wt (lb)	Item Wt (lb)	Comments	Tot. Wt (lb)	Cont. Wt (lb)	Item Wt (lb)	Comments	Tot. Wt (lb)	Cont. Wt (lb)	Item Wt (lb)	Comments	Tot. Wt (lb)	Cont. Wt (lb)	Item Wt (lb)	Comments
1	Wood 2P Desk														315	86	229	Ident Error (See Item 13
2	Wood Table w/Legs	75	93	2	91		93	2	91		93	2	91		95	4	91	
3	Met. File	204	242	64	178		238	60	178		270	92	178		231	53	178	
4	Wood G.P. Cab														273	119	154	Ident Error Probably Desk L
5	Met. 8kcase	245	270	185	85		274	189	85		269	196	73	No. Shelves Not Recrd.	226	141	85	
6	Met. 8kcase	354	400	266	134		405	274	131		402	298	104	No. Shelves Not Recrd.	457	324	133	
7	Met. Bkcase														144	82	62	Ident Error (See Item 14
8	Sofa	140	134	0	134		205	0	205	Did Not Measure Accurate**	216	11	205	Did Not Measure Accurate**	205	0	205	Did Not Measure Accurate**
9	Ped. Chair	47	78	0	78		78	0	78		78	0	78		78	0	78	

TABLE 7 (Continued)

Item No.	Item Description	Meas. Wt* (lb)	Surveyor No. 000				Surveyor No. 001				Surveyor No. 002				Surveyor No. 004			
			Tot. Wt (lb)	Cont. Wt (lb)	Item Wt (lb)	Comments	Tot. Wt (lb)	Cont. Wt (lb)	Item Wt (lb)	Comments	Tot. Wt (lb)	Cont. Wt (lb)	Item Wt (lb)	Comments	Tot. Wt (lb)	Cont. Wt (lb)	Item Wt (lb)	Comments
10	Chair w/Legs	34	25	0	25	Wrong Mat. Type Recorded	44	0	44		44	0	44		44	0	44	
11	Chair w/Legs	34	25	0	25	Wrong Mat. Type Recorded	44	0	44		44	0	44		44	0	44	
12	Misc.	93	82				179				127				0			No Wt. Est. Recorded
13	Wood 1P Desk	232	252	20	232		251	19	232		257	25	232					See Item 1
14	Wood Bkcase	125	164	95	69		199	130	69		215	153	62	Bkcase was Slightly Larger Than Recorded				See Item 7
	TOTAL	1583	1765	631	1052		2010	674	1157		2015	777	1111		2112	809	1303	

* Total wt including contents
**The sofa observed was close to a size category boundary in the transfer function. A difference of one or two inches was critical.

Variability between surveyors and errors of the type noted are to be expected in a survey of this type. Referring to Table 5 and comparing the percent difference between the measured weight for each room with the mean value of the inventory weight obtained by the various surveyors for that room column (1) versus column (3) , the average of the absolute values of the percent difference is seven percent. The same comparison excluding the three rooms with obvious data errors gives two percent. Although these differences are small, it is of interest to investigate the significance of the errors, and in particular their effect on live load variability.

The live load data obtained for these 14 rooms were analyzed to evaluate: (a) surveyor errors and biases, if any, and (b) any evidence of systematic errors in the inventory procedure. The analysis has four sections: (1) preliminary analysis of surveyor bias, (2) estimate of variance of inventory weight, (3) evaluation of systematic errors, and (4) uncertainties for live load expressed in pounds per square foot.

(1) Possible Surveyor Bias or Room-by-Surveyor Interaction

The intercomparison of inventory results by different surveyors was done taking into account the fact that not all surveyors surveyed each room.

The inventory weights were displayed in an array by room and surveyor (Table 8). To evaluate any systematic differences between surveyors (adjusted for differences between rooms), a weighted two-way analysis of variance was performed. Numerican values presented herein were obtained from the OMNITAB computer program. The results are summarized in Table 9. The differences among rooms are, as expected, statistically significant as indicated by the f ratio in Table 9. The differences among surveyors are not significant.

On the basis of an analysis of variance, "computed values" are obtained for comparison with the observed data. They are computed from the estimated average room weight (grand mean in Table 9) plus the appropriate row (room) and column (surveyor) adjustments given in the lower part of Table 9. The differences between observed and computed values, the residuals, are an aid to interpreting the results. "Standardized residuals" are residuals divided by their respective standard deviations.

The standardized residuals shown in Table 10 were examined for any evidence of room-by-surveyor interaction, i.e. to detect effects of any room-plus-surveyor combinations. No such evidence could be seen. Two of the residuals of largest magnitude (exceeding two times their estimated standard deviations) were associated with surveyor number 4 (column 5 in Table 10). Repeating the analysis with surveyor number 4 omitted reduced the residual standard deviation from 233 lbs. to 217 lbs., but the results are qualitatively the same. Surveyor number 4 was not excluded from later analyses.

Large residuals in Table 10 also seem to be associated with Room 419 and 422 (rows 8 and 9). Comparison of the inventory forms prepared by different surveyors for these two rooms may help to identify some of the reasons for discrepancies between surveyors.

TABLE 8 INVENTORY WEIGHTS DISPLAYED BY ROOM AND SURVEYOR

Room No.	OBS. 0	OBS. 1	OBS. 2	OBS. 3	OBS. 4	OBS. 5	OBS. 6
224	0	1353	1385	0	0	1781	0
228	0	2075	2162	0	0	2312	0
231	0	1923	1924	0	0	1898	0
239	0	3574	0	0	3859	3782	0
305	0	2503	2623	0	0	0	2625
313	0	2508	2539	0	0	2518	0
321	0	3950	3846	0	0	3388	0
419	3292	3632	0	0	2778	2821	0
422	2612	3190	2544	0	3391	0	0
423	1765	2010	2015	0	2112	0	0
523	3638	4000	3763	3751	3767	0	0
526	0	1628	1549	1679	1604	0	0
527	0	2312	2103	0	2307	0	0
634	0	3435	3529	0	0	2922	3469

(Zero entries correspond to missing values)

TABLE 9 SUMMARY OF WEIGHTED TWO-WAY ANALYSIS OF VARIANCE FOR INVENTORY WEIGHTS

Analysis of Variance for Two-Way 14 x 7 Table

Effect	Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F. Prob.
Rows (Rooms)	Between Rows	13	28835119.	2218086.1	40.936	.000
	Between Cols	6	1123546.2	187257.71		
	Residuals	29	1571353.8	54184.613		
	Total	48	31530023.			
Column (Surveyors)	Between Rows	13	29704043.	2284926.3	.783	.590
	Between Cols	6	254623.35	42437.225		
	Residuals	29	1571353.8	54184.613		
	Total	48	31530023.			

A Weighted Least Squares Analysis Using
49 Non-Zero Weights and 49 Zero Weights in Column 1

Coefficient	Estimate	Std. Dev.
Grand Mean	2657.5793	46.330293
Row 1	-1130.2603	131.26906
Row 2	-453.58364	131.26906
Row 3	-721.59364	131.26906
Row 4	1070.3522	132.85232
Row 5	-123.20998	143.27476
Row 6	-114.92697	131.26906
Row 7	1091.4064	131.26906
Row 8	501.38036	118.29704
Row 9	289.64425	118.13360
Row 10	-669.10575	118.13361
Row 11	1130.9404	111.55496
Row 12	-1072.6907	122.87425
Row 13	-465.94654	116.27035
Row 14	667.60397	121.96944
Column 1	-144.04410	119.51660
Column 2	63.349267	70.078650
Column 3	-32.680910	73.605892
Column 4	28.295895	163.82179
Column 5	61.481534	92.964220
Column 6	-93.625355	94.174560
Column 7	117.22367	173.04572
Residual	————	232.77589

TABLE 10 STANDARDIZED RESIDUALS FROM TWO-WAY ANALYSIS OF VARIANCE OF INVENTORY WEIGHTS

14 x 7 Table of Residuals, Standardized by Dividing Each Residual by Its Standard Deviation

Row \ Column	1	2	3	4	5	6	7
1	.00	-1.31	-.61	.00	.00	1.95	.00
2	.00	-1.06	-.05	.00	.00	1.13	.00
3	.00	-.42	.11	.00	.00	.31	.00
4	.00	-1.20	.00	.00	.40	.84	.00
5	.00	-.55	.70	.00	.00	.00	-.19
6	.00	-.54	.16	.00	.00	.39	.00
7	.00	.76	.72	.00	.00	-1.50	.00
8	1.60	2.15	.00	.00	-2.40	-1.34	.00
9	-1.09	.94	-1.96	.00	2.06	.00	.00
10	-.45	-.22	.31	.00	.33	.00	.00
11	-.04	.76	.04	-.46	-.44	.00	.00
12	.00	-.11	-.02	.46	-.23	.00	.00
13	.00	.30	-.52	.00	.29	.00	.00
14	.00	.25	1.26	.00	.00	-1.70	.19

(Zero entries correspond to missing values)

The analyses summarized in Tables 8 through 10 were repeated for the two inventory subtotals - estimated weight and weight of paper and books - and for the percent difference between inventory and measured weights (column 6 in Table 5). The tables are not included here since examination of the results revealed nothing more than has been discussed for the case of inventory weights.

On the basis of these two-way analyses of variance, it appears to be satisfactory to proceed to further analyses in which the identities of the surveyors are ignored. That is, the three or more surveyors who did each room are treated as if they were a random sample of the set of surveyors. Differences among surveyors are interpreted as the result of a general tendency to make some errors, since there was no evidence that any surveyor erred consistently in such a way as to over- or underestimate the inventory weight.

(2) *Estimate of Variance of Inventory Weight*

Variability from surveyor to surveyor in the results of the inventory procedure occurs because surveyors do not exactly agree on "estimated weights" and on descriptions and dimensional measurements recorded for furniture, equipment, and paper and books. For a given room, with fixed contents, this kind of variability will be called "surveyor error." The variance due to surveyor error is estimated from the results of repeated surveying [Section (2.2)].

An additional source of variability in the results of the inventory procedure is the difference between actual weights and weights calculated from the "transfer functions." The pilot survey provides very little direct data for estimating this component of variance, since the sample of rooms is small and most of the furniture is standard Government-issue.

For a fixed room, the differences between actual and inventory weights of furniture items are fixed, of course (except for "surveyor error"); they acquire the character of random variation only when a set of rooms is sampled from a larger population. The inventory procedure does, however, provide a computed standard deviation based on the standard deviations associated with the transfer functions [column (2) in Table 6]. This is the best available measure of the contribution of this source of variability to the overall uncertainty of the inventory procedure [Section (2.3)].

Paper and books make up a substantial fraction of the total live load. A special analysis of the surveyor-to-surveyor variability was done for this subtotal of the inventory weight [Section (2.4)].

The results of the studies of variance components are summarized and a combined estimate of the total uncertainty of the inventory procedure is given in Section (2.5).

First, in Section (2.1), the general ideas for the evaluation of variance estimates are discussed.

(2.1) Relation of Variability to Room Weight

Variability of inventory weights might be expected to depend to some degree on the magnitude of the live load in a room. For each of the variance components, three alternative forms of this relationship are compared:

(1) constant variance,

(2) variance proportional to total weight (roughly equivalent to variance proportional to number of items inventoried),

(3) variance proportional to squared total weight (i.e., standard deviation proportional to total weight; constant relative standard deviation).

Let s_j denote the standard deviation (square root of variance) for the j-th room, and let M_j denote an appropriate measure of the total weight in the room. According to the three possibilities listed above, one of the following quantities would appear to be reasonably constant from room to room:

(1) s_j

(2) $s_j / \sqrt{M_j}$

(3) s_j / M_j

Since the number of surveyors is small for each room (3, 4, or 5), one would expect to see a lot of sampling variability between rooms. (Sampling variability is more pronounced for standard deviations than it is for averages.) To assess this sampling variability, the values of each of the three measures of variability were tested for homogeneity.

Two tests for homogeneity of variance were used, Bartlett's and Cochran's.

<u>Notation</u>

t_j = one of the three quantities above, for j-th room

n_j = number of surveyors, for j-th room

$N = \Sigma n_j$

k = number of rooms

$s_p^2 = \Sigma(n_j - 1)\, t_j^2 / (N - k)$

Bartlett: $M = (N - k)\ell n\, s_p^2 - \Sigma(n_j - 1)\ell n\, t_j^2$

Cochran: $C = \text{largest } t_j^2 / \Sigma t_j^2$

The test of significance for Bartlett's M is described in Reference 9 (page 309). Cochran's test (Reference 9, page 310) can only be used when all the n_j are equal. This test was done for two subsets of the rooms - 7 rooms for which $n_j = 3$ and 6 rooms for which $n_j = 4$.

The critical values for the tests of homogeneity, which must be exceeded by the test statistics for rejection of the null hypothesis of homogeneity at the specified probability levels are:

	Probability	.05	.01
Cochran's C	(7 samples of 3)	.5612	.6644
	(6 samples of 4)	.5321	.6258
Bartlett's M		25.6	31.5

To aid in interpretation of the formal tests of significance, the variance measures t_j^2 were also shown on probability plots. If the values of t_j are different only because of sampling variability, then the values ordered from smallest to largest can be compared to percent-points of the chi-squared distribution. The probability plots were done in pairs, first for the seven rooms with $n_j = 3$, and second for the six rooms with $n_j = 4$ (actually for seven rooms, since the room with $n_j = 5$ was included in this set for plotting).

In order that horizontal and vertical scales be the same in all the probability plots, the values of t_j^2 were divided by the appropriate pooled measure s_p^2, and the percent points of the chi-squared distribution were divided by the value of degrees-of-freedom $\nu = (n_j - 1)$, 2, or 3. The plotting positions for the ordered values of t_j^2 were the percent points of χ^2/ν corresponding to probabilities $j / (N + 1)$, i.e. $^1/_8, \ldots, ^7/_8$.

Percent Points of χ^2/ν

j	ν=2	ν=3
1	.13	.23
2	.29	.40
3	.47	.59
4	.69	.79
5	.99	1.04
6	1.51	1.38
7	2.13	1.95

Note that the tests for homogeneity of variance, and the probability plots are approximate to the extent that the data are not exactly normally distributed.

(2.2) Variability Due to Surveyor Error

For each room, the sample variance calculated from the several inventory weight values is an estimate of the variance due to surveyor error. The calculated standard deviations are shown in Table 11. The measured weight for each room is used as the measure M_j of the total weight in the j-th room. Table 11 also shows the standard deviation s_j divided by $\sqrt{M_j}$ and s_j / M_j (the latter multiplied by 100 to be read as a percent.)

To facilitate examination of the effect of M_j, the rooms are listed in Table 11 in order of increasing values of M_j. Although there is a great deal of sampling variability, the larger values of s_j do appear to be associated with the larger values of M_j. The coefficient of variation appears to be the most appropriate measure of variability for surveyor error. The results of the tests for homogeneity of variance are not perfectly clear-cut in Table 11. The Bartlett statistic and one of the Cochran statistics have their smallest values for the coefficient of variation. The tests of significance indicate that the surveyor error variability may not be the same for all rooms. (All values of M and one value of C are "significant" at the .01 probability level.) This might be interpreted to mean that surveyor errors are occasionally larger than those predicted by normal distribution theory.

The pooled estimate, coefficient of variation for surveyor error of 8.33 percent, is valid without depending on normal distribution theory. But note that "two-sigma" types of multiples of this estimate must be interpreted with caution.

(2.3) Variability Due to Transfer Functions

For each surveyor, the inventory procedure produced a standard deviation [column (2) in Table 6] computed from the standard deviations associated with the transfer functions. The average of the squares of these standard deviations is an estimate of the variance due to use of transfer functions for each room. The corresponding standard deviations are given in Table 12.

Each of the three variability measures s_j, $s_j / \sqrt{M_j}$, and s_j / M_j gives values well within the range expected due to sampling variability. (No "significant" test statistics.) The values of the test statistics seem to suggest that the transfer function variance is constant instead of depending on the total weight of room contents; this is a surprising result. Because other variabilities seem to be best described by the coefficient of variation, and since the assumption of constant coefficient of variation is not rejected by the significance tests, the coefficient of variation is suggested as a measure of transfer function variability.

TABLE 11 STANDARD DEVIATIONS FOR SURVEYOR ERROR

Room No.	Measured Wt. (lb) M_j	Standard Dev. (lb) s_j	$\frac{s_j}{\sqrt{M_j}}$	Coeff. of Var. $\frac{s_j}{M_j} \times 100$
526	1271	54	1.51	4.25
224	1508	238	6.13	15.78
423	1583	148	3.72	9.35
231	1953	15	.34	.77
305	2083	70	1.53	3.36
228	2148	120	2.59	5.59
527	2203	125	2.66	5.67
313	2645	16	.31	.60
422	3031	420	7.63	13.86
419	3129	407	7.28	13.01
634	3354	281	4.85	8.38
523	3597	132	2.20	3.67
239	3774	147	2.39	3.90
321	3840	299	4.83	7.79
	Pooled (ν=2)	164	3.29	7.25
	Pooled (ν=3)	277	5.13	9.74
	Pooled (all)	225	4.23	8.33
	Cochran (n=3)	.4770	.4953	.6762
	Cochran (n=4)	.3823	.3686	.3374
	Bartlett	39.2929	34.1754	32.4512

Note: Rooms are listed in order of increasing measured weight.

TABLE 12 STANDARD DEVIATIONS FOR TRANSFER FUNCTION ERROR

Room No.	Measured Wt. (lb) M_j	Standard Dev. (lb) s_j	$\frac{s_j}{\sqrt{M_j}}$	Coeff. of Var. $\frac{s_j}{M_j} \times 100$
526	1271	86	2.41	6.77
224	1508	123	3.17	8.16
423	1583	101	2.54	6.38
231	1953	73	1.65	3.74
305	2083	106	2.32	5.09
228	2148	134	2.89	6.24
527	2203	77	1.64	3.50
313	2645	100	1.94	3.78
422	3031	103	1.87	3.40
419	3129	101	1.81	3.23
634	3354	78	1.35	2.33
523	3597	110	1.83	3.06
239	3774	114	1.86	3.02
321	3840	96	1.55	2.50

Pooled (ν=2)	108	2.27	5.00
Pooled (ν=3)	92	1.98	4.58
Pooled (all)	100	2.08	4.61
Cochran (n=3)	.2193	.2776	.3802
Cochran (n=4)	.2104	.2739	.3631
Bartlett	1.9077	3.9557	10.6749

The pooled estimate, coefficient of variation for transfer function error, is 4.61 percent.

(2.4) Surveyor and Transfer Function Error, Paper and Books

For the weight of paper and books, differences between surveyors led to the standard deviations shown in Table 13. In this table, rooms are listed in order of increasing value of the average inventory weight subtotal for paper and books.

In this case, the tests for homogeneity of variance reject the assumption that the variance is constant. The coefficient of variation is again suggested as the appropriate measure of variability.

The pooled estimate, coefficient of variation for surveyor error (paper and books only), is 13.90 percent.

This separate analysis of the surveyor error for paper and books has been done because paper and books are a substantial fraction of total weight. Also, the standard deviations shown in Table 13 are substantial parts of the corresponding standard deviations in Table 11. In fact, for 4 of the 14 rooms, the standard deviation for paper and books is larger than the standard deviation for surveyor error for the total inventory weight. That is, the numbers in column (4) of Table 6 are more variable than those in column (1). See, for example, room 228. The errors in paper and book recording were offset by opposite errors in other parts of the inventory procedure for these rooms.

The transfer functions (Reference 5, Table 13) are accompanied by standard deviations: the indicated values are roughly equal to 10 percent of the weight (lb per inch) established for each size class. The computed standard deviation for a pile of paper or books is defined in Section 4.2.2.2.2 of Reference 6. The computation allows for errors up to one-half unit in the last figure recorded by the surveyor for the height of the pile and makes a similar allowance for round-off of the estimated compaction factors. The effect of the weight standard deviation is assumed to be proportional to the height of the pile. The transfer function error can be thought of as reflecting (i) variations in the weight of paper and binding materials and (ii) deviations from the exact volume imputed to the recorded quantity (inches) of paper in a particular size class. Surveyor error includes (iii) dimensional measurement errors leading to different size classes as well as to variability in the number of inches within a size class and (iv) errors due to the approximation embodied in the compaction factor. The transfer function and its associated standard deviation were based in part on experimental weighings. Thus, the question arises whether any surveyor error is being "double-counted." Considering the four sources of errors described above, it seems the overlap is very small if there is any at all.

The piles of paper and books were not weighed separately so bias associated with this part of the inventory procedure cannot be assessed separately.

TABLE 13 STANDARD DEVIATIONS FOR SURVEYOR ERROR
(PAPER AND BOOKS ONLY)

Room No.	Measured Wt. (lb) M_j	Standard Dev. (lb) s_j	$\frac{s_j}{\sqrt{M_j}}$	Coeff. of Var. $\frac{s_j}{M_j} \times 100$
526	233	36	2.36	15.45
224	313	69	3.90	22.04
231	406	28	1.39	6.90
305	436	88	4.21	20.18
228	649	150	5.89	23.11
423	649	43	1.69	6.63
313	836	40	1.38	4.78
419	867	112	3.80	12.92
527	875	103	3.48	11.77
523	1029	72	2.24	7.00
634	1133	159	4.72	14.03
239	1331	60	1.64	4.51
422	1476	254	6.61	17.21
321	2352	366	7.55	15.56
	Pooled (ν=2)	158	4.33	15.86
	Pooled (ν=3)	139	4.10	13.42
	Pooled (all)	141	4.03	13.90
	Cochran (n=3)	.7657	.4343	.3034
	Cochran (n=4)	.5557	.4327	.2739
	Bartlett	35.4721	18.5182	15.1760

Note: Rooms are listed in order of increasing average inventory weight subtotal for paper and books.

(2.5) Summary

The variance for the inventory weight of a room, including both surveyor variability and transfer function errors, is estimated by the sum of the two variance components. The room-by-room estimates are shown in Table 14 as standard deviations (square root of the sum of squares of corresponding standard deviations in Tables 11 and 12).

The coefficient of variation is, as expected from the previous results, found to be the appropriate measure of variability. See Figures 4 to 9 in addition to the test statistics in Table 14.

The pooled estimate can be calculated in two ways. First, there is the value 9.52 percent shown in Table 14. Alternatively, one can calculate the square root of the sum of squares of the pooled estimates from Tables 11 and 12; this value is 9.52 percent also.

Rounding off, we find the standard deviation of the inventory procedure is 10 percent of the inventory weight. This is a measure of the variance about the average for surveyors and the assigned values in the transfer functions; it does not include the effect of biases in either of them, discussed in the next section. Conventional probability statements associated with multiples of the estimated standard deviation should be interpreted with caution since there is evidence (Figures 4 through 9) that the inventory weight data are not normally distributed. (That is, the measurement errors in repeated inventorying of the same room may not be normally distributed.)

(3) *Evaluation of Systematic Error in Inventory Procedure*

There are two possible sources of systematic error in the inventory procedure: the transfer functions and surveyor bias. The two kinds cannot be separated from each other in the data available here.

It was found in Section (1) above that none of the surveyors seemed to be biased with respect to the others in the group. The remaining possibility is that surveyors as a group are biased, i.e. that the average of repeated inventorying of a fixed room by many surveyors would be different from the measured weight for reasons other than transfer function error (general tendency to under- or overestimate dimensions, for example, or tendency to omit items).

The inventory data for any one of the 14 rooms in this survey are "correlated" with respect to estimating systematic error since the same transfer function error is present for each surveyor. We have, however, 14 room-averages of inventory weights. These are shown in Table 15 along with percent differences from measured weight. Notice that half the differences are positive and half negative.

Notice also that the large percent differences are not associated with rooms in which there were large differences among surveyors. In fact, two of the three largest surveyor-error variance estimates were obtained in rooms 224 and 419 which have the smallest (in magnitude) percent differences. (Compare with Table 11.)

TABLE 14 STANDARD DEVIATIONS FOR INVENTORY TECHNIQUE
(SURVEYOR AND TRANSFER FUNCTION ERRORS COMBINED)

Room No.	Measured Wt. (lb) M_j	Standard Dev. (lb) s_j	$\frac{s_j}{\sqrt{M_j}}$	Coeff. of Var. $\frac{s_j}{M_j} \times 100$
526	1271	101	2.83	7.95
224	1508	268	6.90	17.77
423	1583	179	4.50	11.31
231	1953	74	1.67	3.79
305	2083	127	2.78	6.10
228	2148	180	3.88	8.38
527	2203	147	3.13	6.67
313	2645	101	1.96	3.82
422	3031	433	7.86	14.29
419	3129	420	7.51	13.42
634	3354	291	5.02	8.68
523	3597	172	2.87	4.78
239	3774	186	3.03	4.93
321	3840	314	5.07	8.18

Pooled (ν=2)	196	4.00	8.81
Pooled (ν=3)	292	5.50	10.76
Pooled (all)	247	4.72	9.52
Cochran (n=3)	.3662	.4254	.5813
Cochran (n=4)	.3659	.3407	.2936
Bartlett	17.9052	14.0681	14.1362

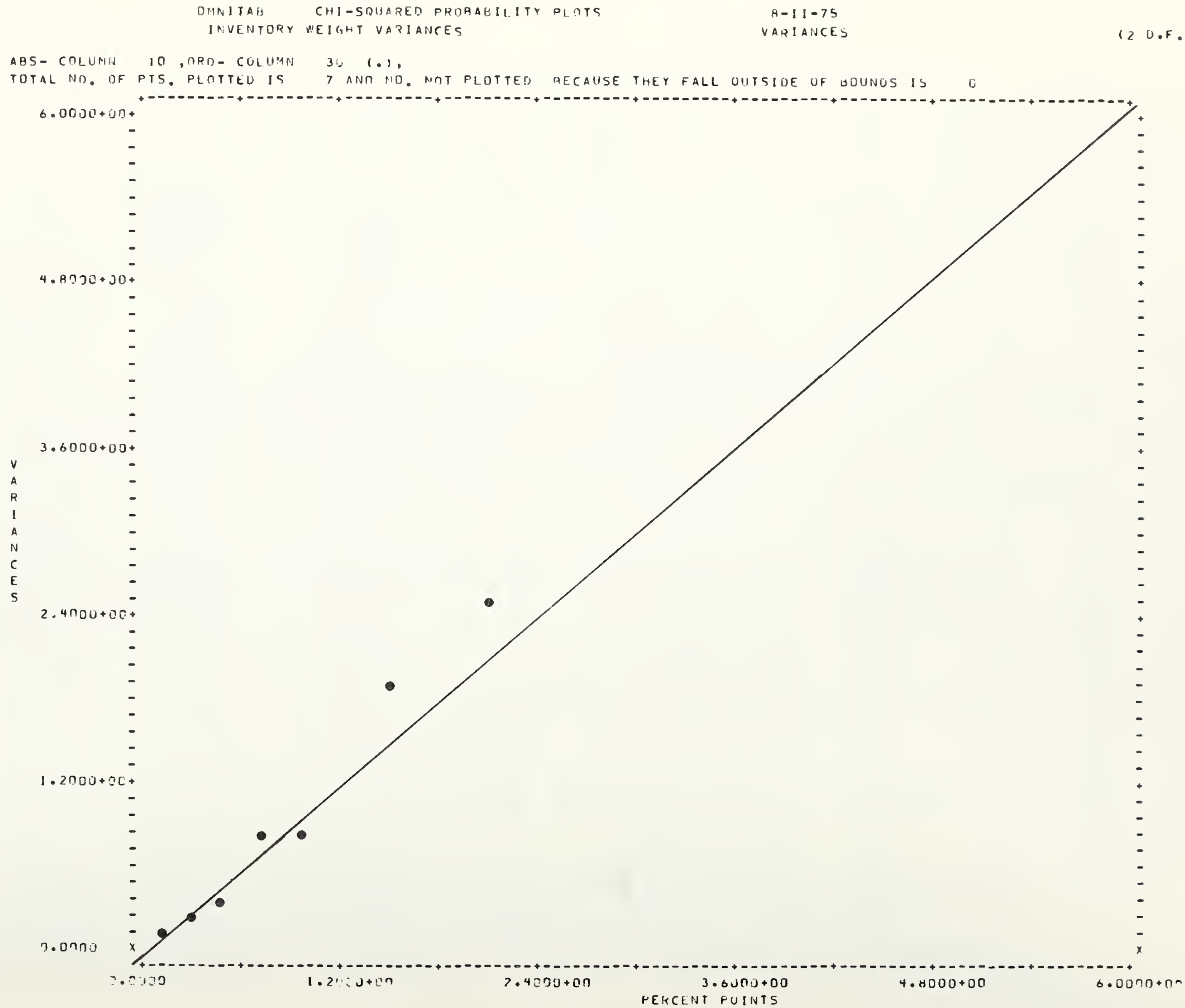


Figure 4 Variances - 2 Degrees of Freedom

OMNITAB CHI-SQUARED PROBABILITY PLOTS 8-11-75
INVENTORY WEIGHT VARIANCES VARIANCES (3 D.F.)

ABS- COLUMN 20 ,ORD- COLUMN 31 (.),
TOTAL NO. OF PTS. PLOTTED IS 7 AND NO. NOT PLOTTED BECAUSE THEY FALL OUTSIDE OF BOUNDS IS 0

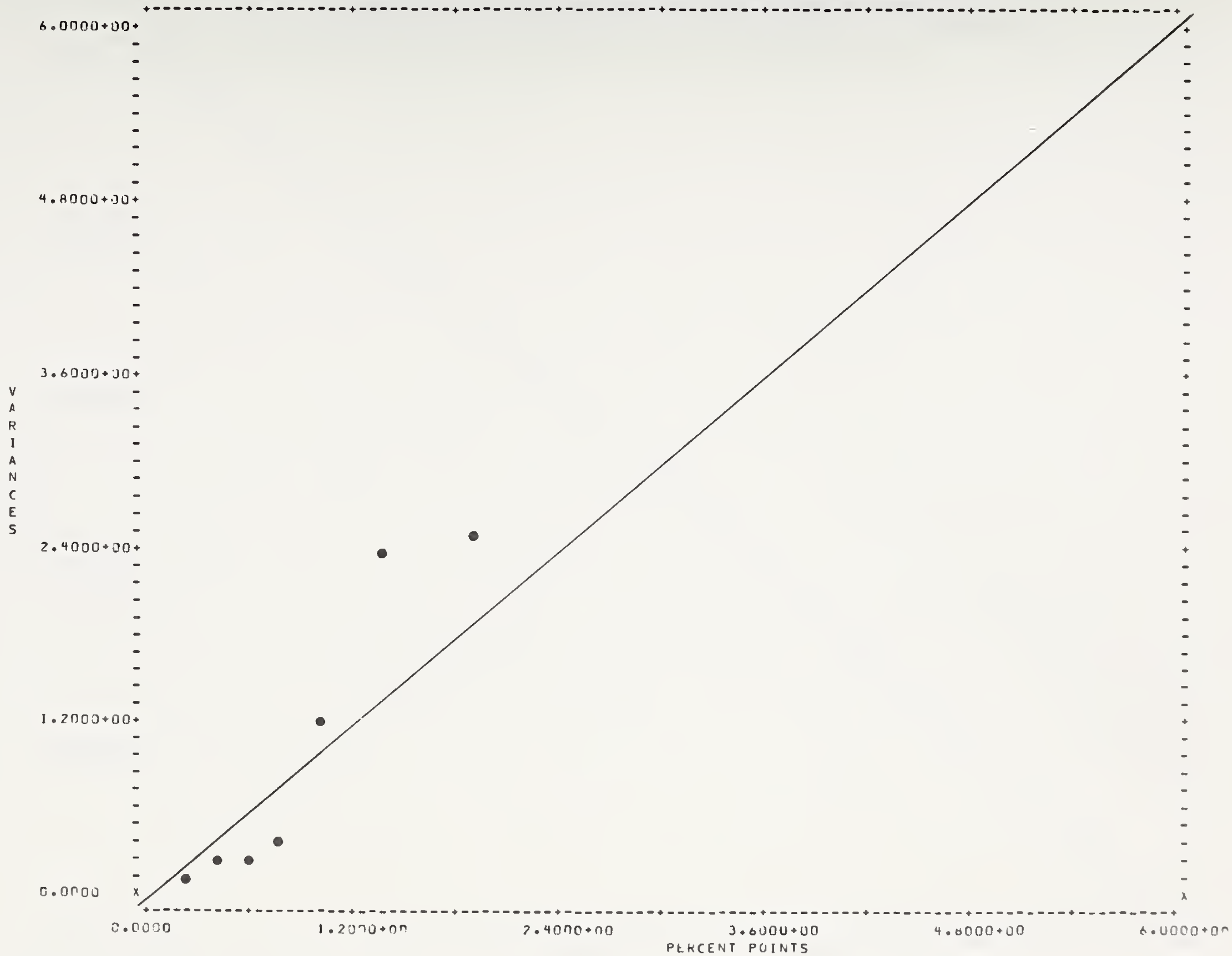


Figure 5 Variances - 3 Degress of Freedom

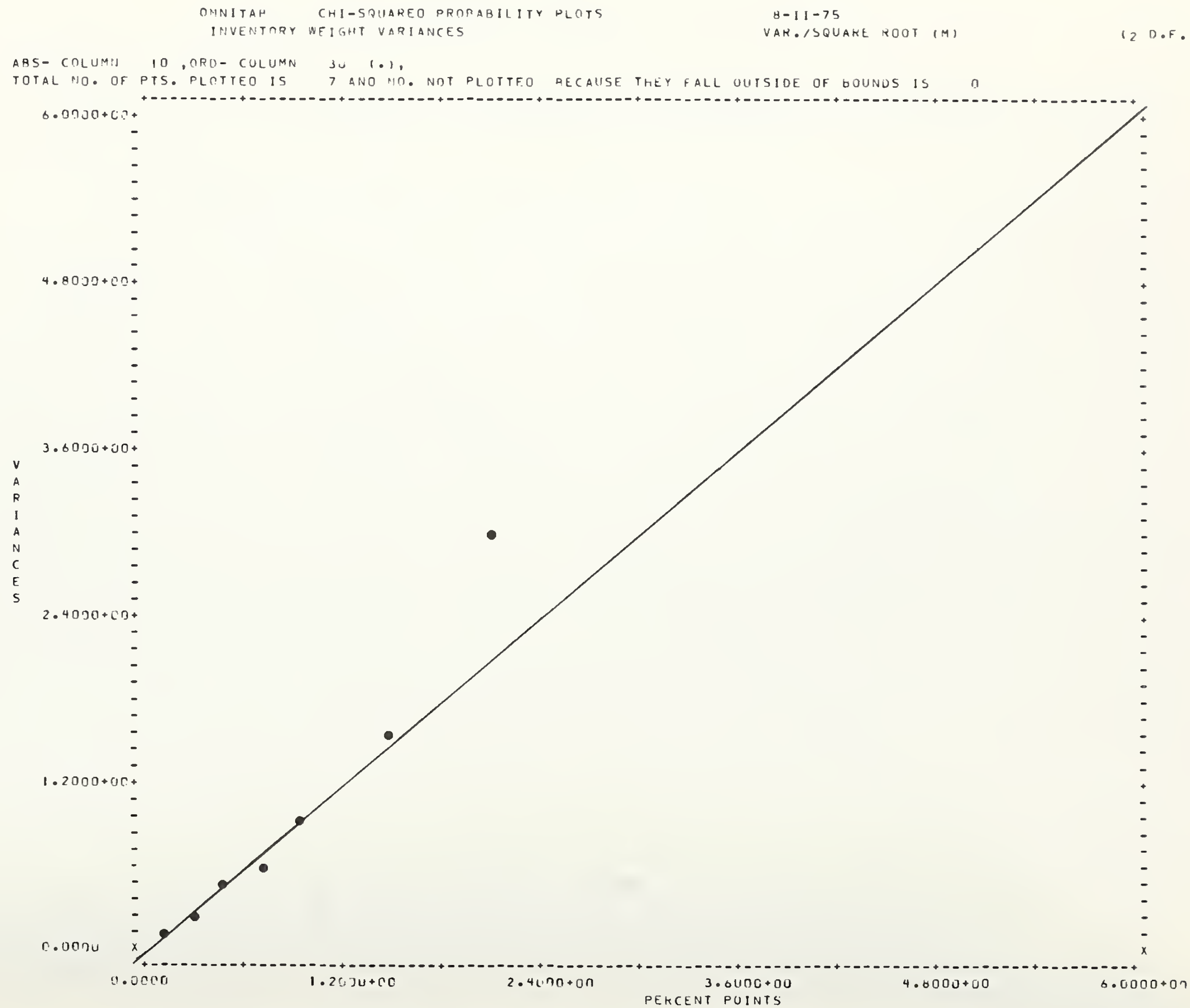


Figure 6 Variance/Square Root M - 2 Degrees of Freedom

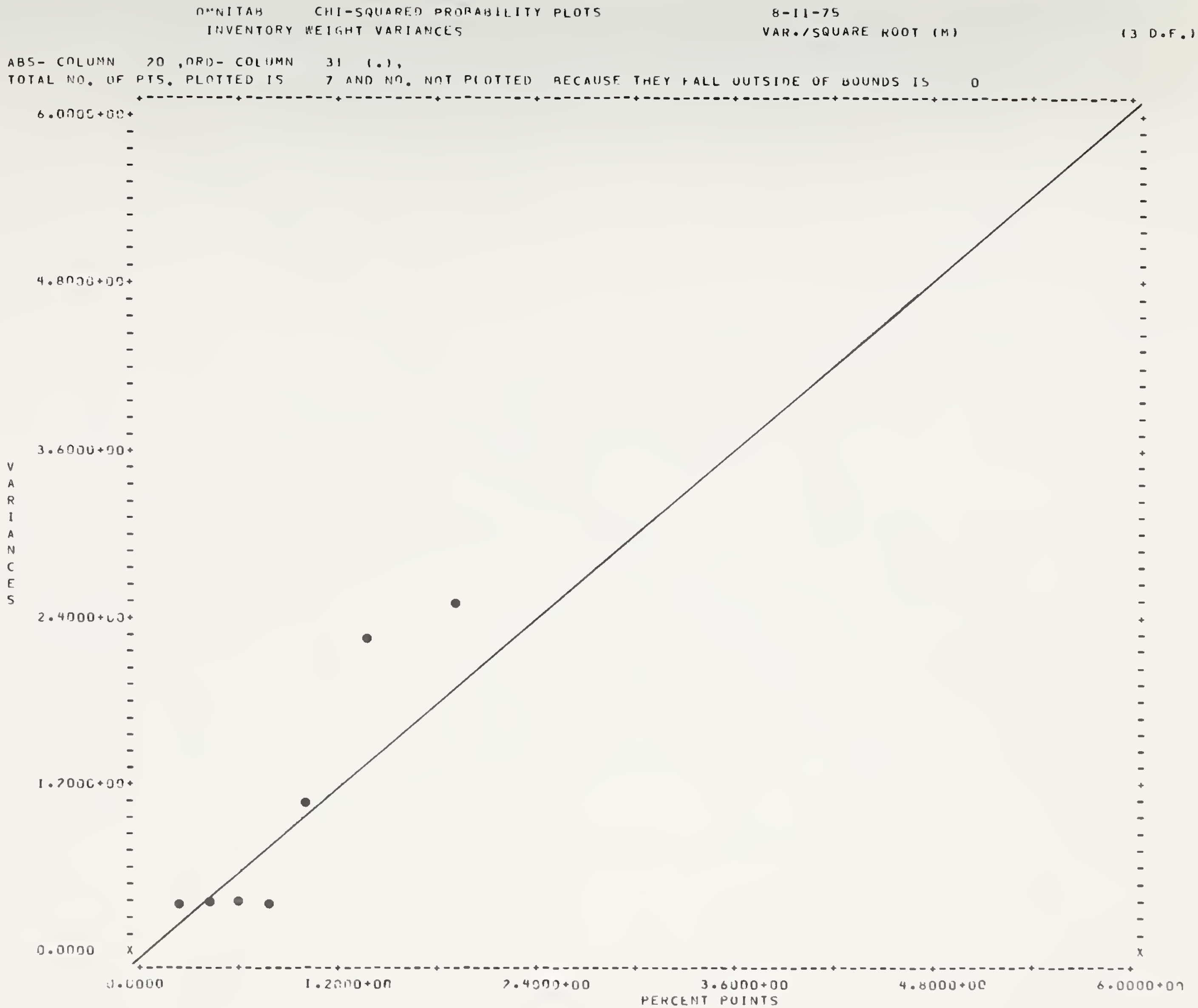


Figure 7 Variance/Square Root M - 3 Degrees of Freedom

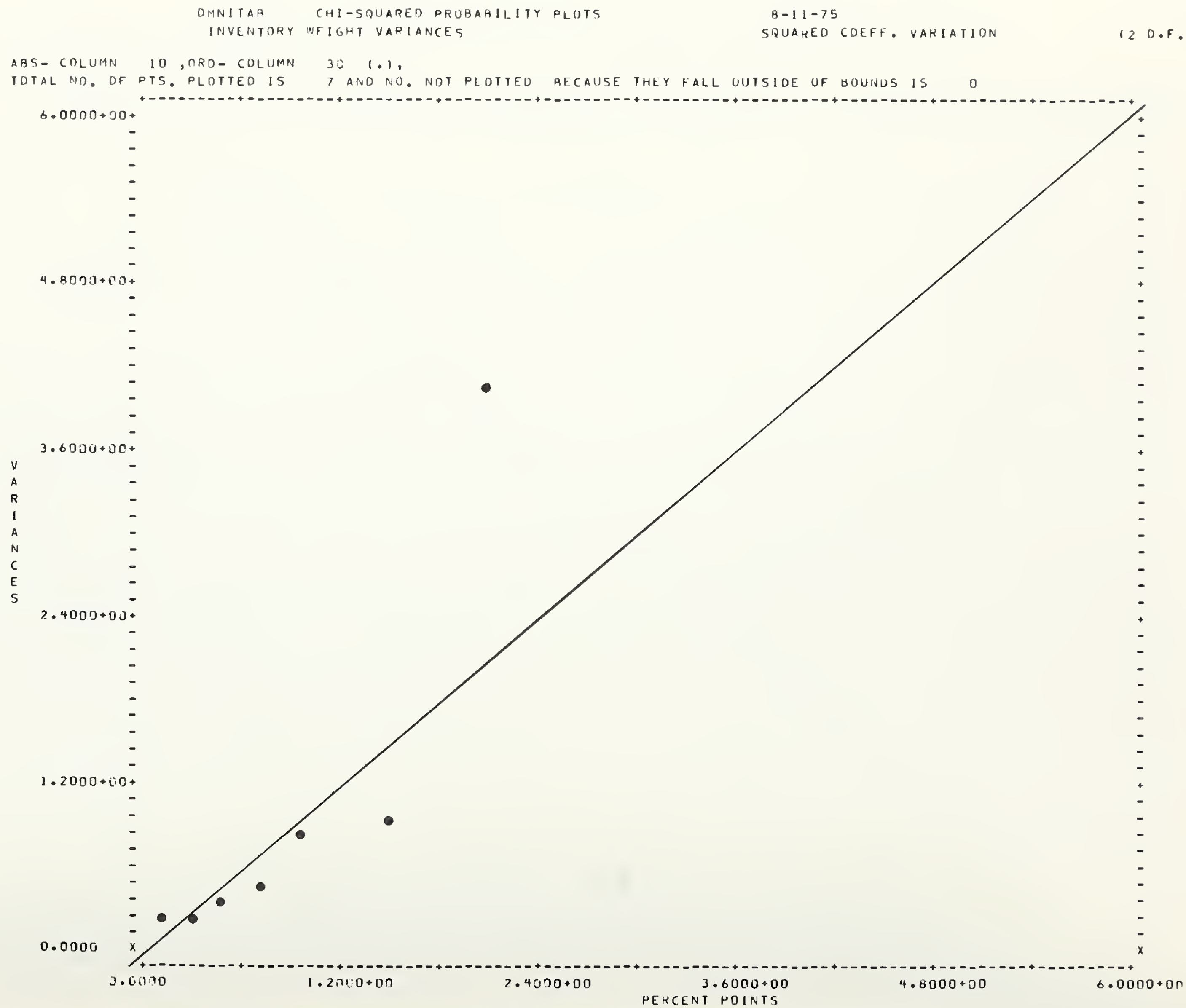


Figure 8 Squared Coefficient of Variation - 2 Degrees of Freedom

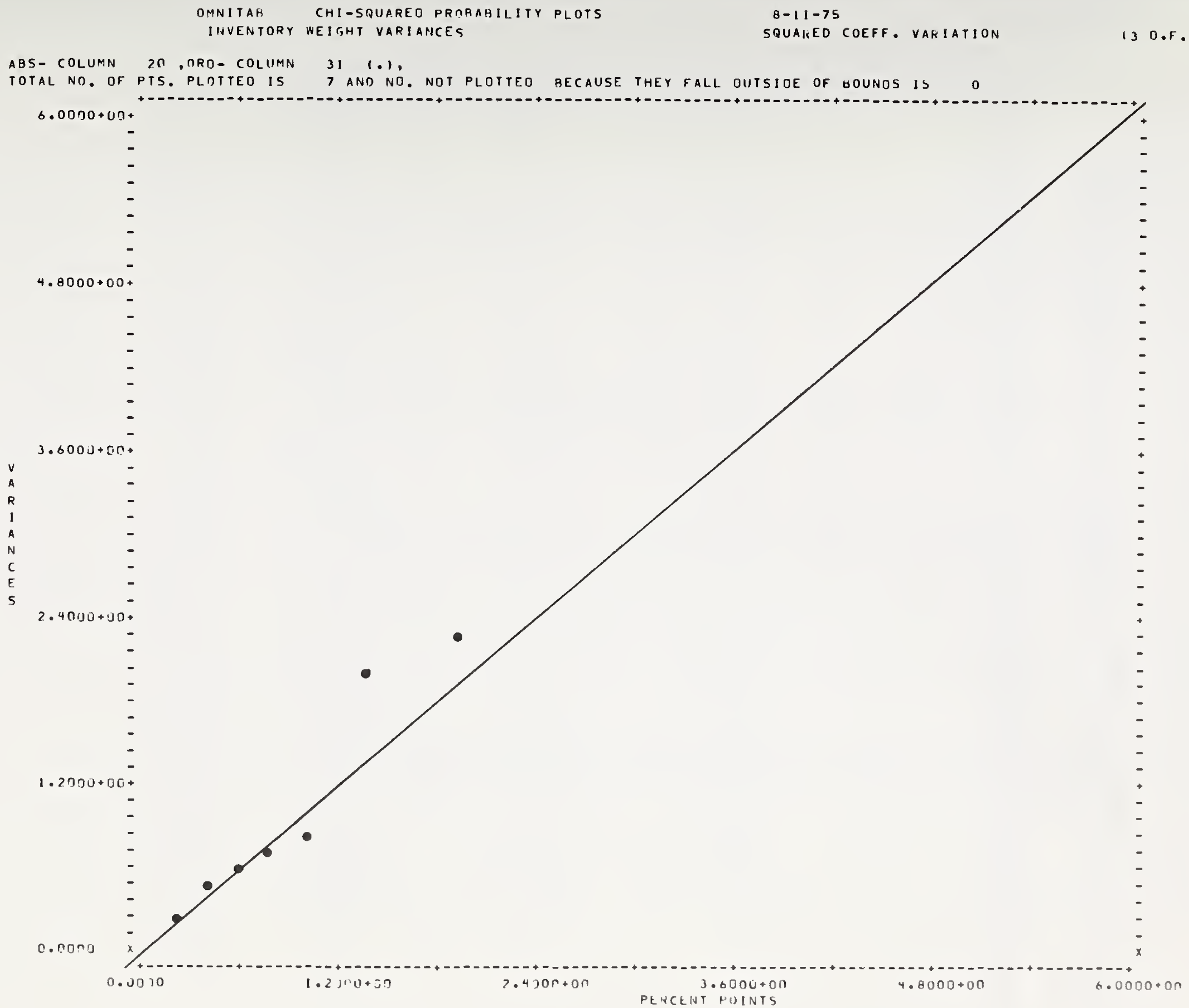


Figure 9 Squared Coefficient of Variation - 3 Degrees of Freedom

TABLE 15 MEASURED WEIGHTS AND AVERAGE INVENTORY WEIGHTS

Room No.	Measured Wt. (lb) (1)	Average Inventory Wt. (lb) (2)	Percent Difference $\frac{(1) - (2)}{(1)} \times 100$ (3)
224	1508	1506	0.13
228	2148	2183	-1.63
231	1953	1915	1.95
239	3774	3738	0.95
305	2083	2584	-24.04
313	2645	2522	4.65
321	3840	3728	2.92
419	3129	3131	-0.06
422	3031	2934	3.19
423	1583	1975	-24.79
523	3597	3784	-5.19
526	1271	1615	-27.06
527	2203	2207	-0.18
634	3354	3339	0.45

Using the results of Section (2), a percent difference in Table 15 should have variance

$$(\text{Transfer Function Variance}) + \frac{(\text{Surveyor Error Variance})}{n}$$

where n is the number of surveyors who inventoried the room. For the seven rooms on the third and fourth floors, n=3. For the seven rooms on the fifth, sixth, and seventh floors, n=4 (except room 523 with n=5). Using the pooled values from Tables 11 and 12 gives:

$$(4.61)^2 + \frac{(8.33)^2}{3} = (6.66)^2 \ ,$$

$$(4.61)^2 + \frac{(8.33)^2}{4} = (6.21)^2 \ .$$

All but three of the percent differences in Table 15 are smaller than these values. The three values of about -25% are roughly three times their standard deviations. In the following discussion, data for all 14 rooms are analyzed simultaneously, ignoring (as a second-order effect) the theoretical difference in the standard deviations. The standard deviation for the percent difference is taken to be 6.5.

The average of the percent differences is -4.91 and its standard error is $6.5 / \sqrt{14} = 1.74$. If the measurement errors in the inventory data were normally distributed, the average should lie within $\pm$ 2.160 times its estimated standard error for a confidence level 0.95 or $\pm$ 3.012 for a confidence level of 0.99. These confidence intervals (based on Student's t) for the average percent difference include zero at the 99% level, but not at the 95% level.

The analysis based on normal distribution theory can be challenged. Assuming approximately constant coefficient of variation, the percent differences should be distributed about some average value (the systematic error, not necessarily zero), with standard deviation 6.5. The computed standard deviation for column (3) of Table 15, however, is 11.3. Considering the small sample sizes, the two values are not inconsistent. But, it must be noted that the percent differences tended to be more variable than was predicted from the analysis of inventory data.

A distribution-free analysis has also been done. (This reduces the effect on the results of the three 25% deviations.) The hypothesis that the systematic error is zero cannot be rejected at the 95% level by the Wilcoxan signed-ranks test (Reference 10, Chapter 5.1). A 95% confidence interval, associated with the test, is:

$$-12.2\% \leq \text{bias} \leq +1.5\%$$

A "robust" estimate of the bias is -0.8 percent.

In conclusion, the data suggest the possibility of systematic error but the error, if any, appears to be small with respect to the variance of the inventory procedure. The estimated 10 percent coefficient of variation for the survey procedure overwhelms a possible one to five percent bias. The systematic error, if any, leads to overestimation of live loads.

(4) *Measurement Uncertainty for Live Load*

Up to now, this analysis has been conducted in terms of total weights in pounds. An analysis performed in live load units (pounds per square foot) would differ only very slightly since 12 of the 14 rooms had areas of 177 to 180 square feet. (Exceptions: Room 422, 163 ft^2; Room 526, 265 ft^2.) Coefficients of variation would not change at all since the conversion from lbs. to psf would affect both numerator and denominator of the ratio.

The principal result from this analysis is that the variability of live load due to the survey procedure, including transfer functions and surveyor errors, is estimated to be 10 percent of the measured load. The systematic error, if any, is essentially negligible in comparison with the statistical variability; there may be a very slight tendency for the inventory weight to overestimate the actual weight.

The "measurement error" associated with the survey problem is, in turn, negligible with respect to the variability of live loads from room to room in office buildings. For 149 rooms in the NBS building, the average live load was 15.7 psf, with a standard deviation of 8.2 psf. The coefficient of variation exceeds 50 percent.

Since the total coefficient of variation, including the variability of live loads and the "measurement error," is estimated by the sum of the two components, i.e.:

$$(50)^2 + (10)^2 \cong (51)^2$$

it is evident that where the room-to-room variability is about 50 percent, the coefficient of variation for loads determined by the inventory procedure with 10 percent variability is negligibly larger.*

Based on the preceding analysis, it was concluded that it was not necessary to account for "measurement errors" associated with the inventory procedure in reducing the survey data.

*For the measured weights of the 14 rooms considered in the report, the average live load was 14.3 psf with standard deviation of 5.2 psf, and coefficient of variation of 36 percent. A 10 percent measurement error would increase this variation to 38 percent. The average live load based on average inventory weights [column (2) in Table 15] is 14.7 psf with a standard deviation of 4.8 psf (c.v. 33%). This is not quite comparable since the averaging of several surveyors would tend to reduce variability.

3.3 Characteristics of Survey Sample

Data on room use and occupancy characteristics are presented in Tables 16 and 17. The classification of firms used in Table 17 was in accordance with standard classifications developed to promote uniformity and comparability in the presentation of statistical data (11).

The number of each type of room in the buildings and the number selected for survey are given in Table 16. General and clerical offices were obviously the most prevalent followed in order by storage areas, conference rooms, lobbies, file rooms, and libraries. There were a number of vacant rooms in most buildings. The number of rooms given in parentheses (except for Buildings 14, 24, and 27) only include the rooms randomly selected on the basis of firm type, room use and room area (5). The additional ten percent sample of adjacent rooms selected to obtain loads for areas larger than an individual office (5) are not included. For Buildings 14 and 27, all the rooms where access was possible were surveyed and these are indicated in parentheses. For a few cases, access could not be obtained for security reasons, etc. In the pilot survey of the NBS Administration Building the twenty-five percent sampling rate was also not used and all the rooms with the exception of three floors were surveyed.

A higher sampling rate was used for Buildings 14, 24, and 27 in order to obtain data to check the mathematical load models developed from the survey data (Section 3.8). Comparing loads predicted for the entire building using these models with the surveyed loads permitted an evaluation of their accuracy as discussed in Section 3.9.

A total of 2,433 rooms was originally selected in the twenty-three buildings. The breakdown of this total according to the selection procedure used was as follows:

Random Selection (excluding Bldgs. 14, 24, & 27). . .	1,376	Total No. Included in Table 16
Random Selection (Bldgs. 14, 24, & 27).	261	
Extra Rooms (Bldgs. 14, 24, & 27)	616	
Adjacent Rooms (Bldgs. 14, 24, & 27).	28	
Adjacent Rooms (excluding Bldgs. 14, 24, & 27). . . .	152	
TOTAL	2,433	

The number of rooms actually used in the data analysis is given in Table 18. As indicated previously, the data for 8.5 percent of the rooms surveyed were discarded due to errors. The numbers for each selection procedure are listed separately in Table 18. Of the 2,226 used, 1,354 were randomly selected, 245 were adjacent rooms, and 627 were extra rooms surveyed in Buildings 14, 24, and 27. The percentage of adjacent rooms selected by the surveyors $\left[\frac{245}{1,354} \times 100 = 18\%\right]$ was higher than originally intended (5). The surveyor errors discussed in Section 2.4, which resulted in discarding

TABLE 16 ROOM USE CHARACTERISTICS OF SURVEY SAMPLE

Bldg. No.	Number of Rooms*							
	General	Clerical	Lobby	Conf.	File	Storage	Library	Vacant
1	84 (19)	16 (3)	5 (1)	8 (1)	1 (1)	4 (1)	1 (1)	1
2	35 (7)	4 (1)	7 (2)	3 (1)	0	7 (1)	1 (1)	56
3	44 (11)	12 (3)	9 (2)	4 (1)	2 (1)	14 (4)	2 (1)	94
5	155 (39)	25 (6)	10 (2)	11 (1)	3 (1)	17 (3)	2 (1)	53
7	35 (10)	11 (2)	2 (1)	3 (1)	0	8 (2)	0	2
8	7 (7)	1 (1)	2 (2)	1 (1)	0	1 (1)	0	5
9	140 (13)	75 (9)	22 (1)	20 (3)	0	88 (11)	5 (1)	29
10	106 (26)	57 (13)	9 (1)	18 (3)	0	41 (8)	0	31
11	18 (4)	11 (2)	0	2 (1)	0	5 (1)	1 (1)	1
12	99 (23)	49 (11)	13 (2)	6 (1)	6 (1)	20 (4)	3 (1)	141
13	138 (31)	32 (7)	3 (1)	17 (3)	0	33 (7)	0	22
14	186 (129)	108 (57)	39 (23)	15 (13)	24 (21)	50 (34)	3 (0)	31
17	121 (30)	94 (24)	10 (1)	14 (2)	10 (1)	11 (2)	4 (1)	18
18	191 (44)	198 (45)	20 (3)	9 (1)	20 (5)	52 (11)	3 (1)	27
19	843 (189)	201 (44)	107 (24)	142 (32)	42 (10)	128 (29)	26 (6)	51
20	45 (10)	16 (4)	8 (1)	2 (1)	2 (1)	11 (2)	0	8
21	58 (13)	26 (5)	7 (1)	15 (4)	18 (4)	7 (1)	0	0
22	1,389 (313)	254 (58)	37 (8)	120 (27)	44 (8)	35 (8)	24 (6)	17
23	45 (12)	7 (1)	3 (1)	4 (1)	0	9 (2)	0	0
24	157 (106)	55 (41)	2 (0)	7 (3)	3 (3)	6 (2)	6 (4)	0
25	49 (12)	25 (6)	8 (1)	8 (1)	2 (1)	17 (3)	1 (1)	16
26	38 (8)	32 (8)	2 (1)	1 (1)	4 (1)	3 (1)	0	5
27	288 (272)	179 (112)	18 (15)	28 (25)	14 (7)	50 (35)	4 (3)	0

*( ) Number of rooms selected exclusive of adjacent rooms - sample for Buildings 14, 24, and 27 includes adjacent and extra rooms

TABLE 17 OCCUPANCY CHARACTERISTICS OF SURVEY SAMPLE

Bldg. No.	Number of Firm Types									
	Agri-Culture	Mining	Construc-tion	Manufac-turing	Transpor-tation	Trade	Finance	Service	Public Admin.	Non Classifiable
1							1			
2						1	1	12	1	
3							6	9		2
5				7	2	1	8	6		2
7			1	1	1		2	2		2
8							1	1		
9				2	3	3	3	27	3	1
10			2	3	1	5	6	28	5	1
11						2		7		
12						3	7	10		
13						1				
14			1	11	1	3	15	13		
17				2	1	2	12	20		
18			1	2	1		16	22	1	
19			2	1	1	20	26	49	2	
20			1		2	2	1			
21								3	4	
22								1	29	8
23								2	10	
24								1		
25					1				9	
26									1	
27								1	5	

TABLE 18 ROOM USE CHARACTERISTICS OF ANALYSIS SAMPLE

Bldg. No.	Total Area of Rooms (ft^2)	Selection Basis	Room Use							
			General	Clerical	Lobby	Conf.	File	Storage	Library	Total
1	6,231	Random	16	2	1	2	1	0	0	22
	514	Adjacent	1	1	0	0	0	0	0	2
2	4,081	Random	6	1	2	1	0	0	1	11
	0	Adjacent	0	0	0	0	0	0	0	0
3	11,698	Random	13	2	0	1	0	3	0	19
	321	Adjacent	1	0	0	1	0	1	0	3
5	13,214	Random	36	8	0	0	1	3	1	49
	898	Adjacent	5	0	0	0	0	0	0	5
7	3,875	Random	8	0	1	1	0	1	0	11
	340	Adjacent	2	0	0	0	0	0	0	2
8	1,969	Random	8	1	1	1	0	1	0	12
	0	Adjacent	0	0	0	0	0	0	0	0
9	27,748	Random	17	4	0	4	0	8	1	34
	605	Adjacent	3	0	0	0	0	0	0	3
10	9,045	Random	29	2	1	4	0	6	0	42
	942	Adjacent	1	0	3	1	0	1	0	6

TABLE 18 ROOM USE CHARACTERISTICS OF ANALYSIS SAMPLE (CONTD.)

Bldg. No.	Total Area of Rooms (ft^2)	Selection Basis	Room Use							
			General	Clerical	Lobby	Conf.	File	Storage	Library	Total
11	1,992	Random	4	2	0	1	0	1	1	9
	200	Adjacent	1	0	0	0	0	0	0	1
12	5,052	Random	18	6	3	0	1	3	0	31
	1,537	Adjacent	3	1	0	0	2	0	0	6
13	17,957	Random	30	7	1	3	0	7	0	48
	2,580	Adjacent	2	0	2	0	0	0	0	4
14	20,512	Random	45	16	6	4	3	8	0	82
	2,408	Adjacent	5	1	1	1	0	1	0	9
	55,629	Extra	117	19	19	11	10	38	1	215
17	9,022	Random	34	16	4	2	1	2	1	60
	1,276	Adjacent	4	0	0	1	0	0	0	5
18	19,064	Random	43	37	3	1	5	8	0	97
	2,634	Adjacent	8	5	1	0	0	2	0	16
19	53,515	Random	162	38	21	31	7	24	5	288
	8,641	Adjacent	35	3	6	5	0	2	0	51
20	3,350	Random	10	4	1	1	1	2	0	19
	206	Adjacent	2	0	0	0	0	0	0	2

TABLE 18 ROOM USE CHARACTERISTICS OF ANALYSIS SAMPLE (CONTD.)

Bldg. No.	Total Area of Rooms (ft^2)	Selection Basis	Room Use							
			General	Clerical	Lobby	Conf.	File	Storage	Library	Total
21	26,479	Random	6	3	0	2	1	3	0	15
	1,805	Adjacent	3	0	0	3	0	0	0	6
22	83,306	Random	220	20	7	26	4	15	1	293
	20,214	Adjacent	95	2	3	4	1	1	0	106
23	3,490	Random	11	2	1	1	0	3	0	18
	0	Adjacent	0	0	0	0	0	0	0	0
24	8,773	Random	25	9	0	1	1	0	1	37
	0	Adjacent	0	0	0	0	0	0	0	0
	29,728	Extra	78	26	0	1	2	2	3	112
25	4,975	Random	9	6	1	1	1	3	0	21
	895	Adjacent	2	0	0	1	0	0	0	3
26	8,014	Random	11	2	1	1	2	1	0	18
	1,130	Adjacent	1	0	0	0	1	0	0	2
27	27,159	Random	60	35	5	7	1	10	0	118
	3,838	Adjacent	7	3	0	1	1	1	0	13
	73,012	Extra	188	56	9	17	6	22	2	300
TOTAL	579,924								TOTAL	2,226

some of the rooms did not seem to be related to the type of the room (general, clerical, etc.). The relative mix of room use types used in the analysis, therefore, was not significantly different from that of the original survey sample selected. For example, 941 of the 1,637 randomly selected rooms in Table 16 or fifty-seven percent were general offices. This changed to sixty-one percent for the analysis sample in Table 18 $\left[\frac{821}{1,354} \times 100\right]$. The changes for the other types of room use were also small.

In general, only the 1,354 randomly selected rooms, of which 1,044 were general and clerical offices, were used in the analyses in Section 3.4 through 3.8. The sample size for some of the room use types was small since a constant sampling fraction was used (5). For example, only one percent $\left[\frac{12}{1,354} \times 100\right]$ of the random sample was libraries. The adjacent rooms were included with these randomly selected rooms in determining the relationship between loads and area in Section 3.6. The extra rooms in Buildings 14, 24, and 27 were only used in the evaluation of the load models in Section 3.9. The number of rooms used in each analysis in Section 3.4 through 3.9 is indicated therein.

The occupancy characteristics for the survey sample given in Table 17 indicate that a majority of the firms were service, finance, or public administration type organizations. For the government buildings (Buildings 21-27), the firms were primarily public administration.

3.4 Influence of Building Characteristics

Fire load and live load data for all the buildings are presented in Tables 19 through 22. Buildings in each Census region are grouped according to height in Tables 19 and 20, and according to age in Tables 21 and 22. Maximum and minimum values and the mean and standard deviation are given for each category. The following relationships were used for the mean and standard deviations throughout this report:

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} X_i$$

$$S = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n-1}}$$

The standard deviation is a measure of data dispersion even for non-normal distributions. For those distributions in this report which do not appear to be normal, an assumption regarding the form of the distribution in addition to the standard deviation and mean are required for estimating fractiles.

The loads are expressed in terms of pounds per square foot (psf) and were obtained by dividing the total load in each room by the floor area of the room. The fire load is the total weight of combustibles converted to an equivalent weight of combustibles with a calorific value of 8000 Btu/lb. No derating factor was applied to the enclosed combustibles such as papers in filing cabinets (5).

The minimum value for the live load is zero in several cases in Tables 20 and 22. Lobbies with no furniture or empty rooms account for these values. The corresponding fire loads, however, are not zero because of the interior finish for the walls, ceiling, and floor.

The data in Tables 19 and 20 do not indicate any definite relationship between load magnitude and building height. For the northeast region the mean load increases with height but there is no consistent trend for the other regions. Tables 21 and 22 seem to indicate a decrease in the mean load with increasing age. The southern region and the oldest building in the western region, however, do not follow this trend. The mean values do appear to vary somewhat with geographic location. The difference in sample size for each region may affect this variation. The three parameters: building height, building age, and geographic location were considered in developing the load models and their influence is discussed further in Section 3.8.

TABLE 19 INFLUENCE OF GEOGRAPHIC LOCATION AND BUILDING HEIGHT ON FIRE LOAD

Census Region	Height Group (No. of Stories)	No. of Bldgs.	No. of Rooms	Total Fire Load (psf)			
				Max.	Min.	Mean	Std. Dev.
Northeast	1 - 5	2	36	19.2	0.9	5.1	4.2
	6 - 10	1	11	17.5	1.4	6.2	4.3
	11 - 20	0	--	--	--	--	--
	> 20	3	362	106.6	0.3	7.9	7.7
	All Bldgs.	6	409	106.6	0.3	7.6	7.4
North-central	1 - 5	3	41	24.0	0.5	6.2	4.3
	6 - 10	0	--	--	--	--	--
	11 - 20	1	34	39.7	1.2	7.4	8.0
	> 20	1	42	19.8	1.4	6.4	4.1
	All Bldgs.	5	117	39.7	0.5	6.6	5.5
South	1 - 5	2	29	39.9	1.1	8.1	7.9
	6 - 10	2	79	45.3	1.6	7.7	6.5
	11 - 20	1	37	31.7	2.6	12.1	6.4
	> 20	1	82	30.4	0.4	7.4	5.9
	All Bldgs.	6	227	45.3	0.4	8.3	6.6
West	1 - 5	2	37	33.3	1.0	8.6	7.5
	6 - 10	1	60	29.0	1.5	5.5	4.0
	11 - 20	2	215	48.5	0.5	5.8	5.9
	> 20	1	289	51.8	0.6	10.1	6.7
	All Bldgs.	6	601	51.8	0.5	8.0	6.6

Government and Private Buildings

(Only those rooms that were randomly selected were used for this table.)

TABLE 20 INFLUENCE OF GEOGRAPHIC LOCATION AND BUILDING HEIGHT ON LIVE LOAD

Census Region	Height Group (No. of Stories)	No. of Bldgs.	No. of Rooms	Live Load (psf) Max.	Min.	Mean	Std. Dev.
Northeast	1 - 5	2	36	35.4	0.2	7.2	6.4
	6 - 10	1	11	21.1	0.4	7.8	6.1
	11 - 20	0	--	--	--	--	--
	> 20	3	362	127.7	0.0	10.6	10.0
	All Bldgs.	6	409	127.7	0.0	10.2	9.7
North-central	1 - 5	3	41	52.7	0.0	8.1	10.0
	6 - 10	0	--	--	--	--	--
	11 - 20	1	34	37.9	1.6	9.0	8.1
	> 20	1	42	25.3	0.1	7.2	4.8
	All Bldgs.	5	117	52.7	0.0	8.0	7.8
South	1 - 5	2	29	38.0	1.8	10.3	9.1
	6 - 10	2	79	74.3	0.2	9.1	10.3
	11 - 20	1	37	43.0	6.4	16.1	8.3
	> 20	1	82	44.6	0.0	9.3	8.0
	All Bldgs.	6	227	74.3	0.0	10.5	9.3
West	1 - 5	2	37	33.4	0.0	12.7	7.7
	6 - 10	1	60	35.4	0.0	6.7	6.3
	11 - 20	2	215	55.6	0.0	8.0	7.2
	> 20	1	289	50.1	0.0	11.5	7.7
	All Bldgs.	6	601	55.6	0.0	9.9	7.7

Government and Private Buildings

(Only those rooms that were randomly selected were used for this table.)

TABLE 21 INFLUENCE OF GEOGRAPHIC LOCATION AND BUILDING AGE ON FIRE LOAD

Census Region	Age Group (Years)	No. of Bldgs.	No. of Rooms	Total Fire Load (psf)			
				Max.	Min.	Mean	Std. Dev.
Northeast	1 - 5	0	--	--	--	--	--
	6 - 10	1	294	106.6	0.3	8.4	8.1
	11 - 20	1	21	17.2	1.1	4.8	3.7
	> 20	4	94	35.1	0.9	5.9	4.9
	All Bldgs.	6	409	106.6	0.3	7.6	7.4
North-central	1 - 5	1	12	14.5	2.3	7.9	3.3
	6 - 10	2	52	39.7	1.2	6.0	6.7
	11 - 20	2	53	24.0	0.5	6.8	4.6
	> 20	0	--	--	--	--	--
	All Bldgs.	5	117	39.7	0.5	6.6	5.5
South	1 - 5	1	48	27.0	1.6	7.0	4.7
	6 - 10	2	29	39.9	1.1	8.1	7.9
	11 - 20	1	37	31.7	2.6	12.1	6.4
	> 20	2	113	45.3	0.4	7.7	6.7
	All Bldgs.	6	227	45.3	0.4	8.3	6.6
West	1 - 5	1	289	51.8	0.6	10.1	6.7
	6 - 10	1	118	44.5	0.5	3.9	4.4
	11 - 20	3	175	48.5	1.0	7.2	5.8
	> 20	1	19	33.3	3.1	9.5	9.0
	All Bldgs.	6	601	51.8	0.5	8.0	6.6

Government and Private Buildings

(Only those rooms that were randomly selected were used for this table.)

TABLE 22 INFLUENCE OF GEOGRAPHIC LOCATION AND BUILDING AGE ON LIVE LOAD

Census Region	Age Group (Years)	No. of Bldgs.	No. of Rooms	Live Load (psf)			
				Max.	Min.	Mean	Std. Dev.
Northeast	1 - 5	0	--	--	--	--	--
	6 - 10	1	294	127.7	0.0	11.4	10.5
	11 - 20	1	21	35.4	2.2	8.3	6.9
	> 20	4	94	33.9	0.0	7.1	5.8
	All Bldgs.	6	409	127.7	0.0	10.2	9.7
North-central	1 - 5	1	12	52.7	1.4	11.2	13.8
	6 - 10	2	52	37.9	0.0	7.5	7.0
	11 - 20	2	53	44.9	0.1	7.8	6.8
	> 20	0	--	--	--	--	--
	All Bldgs.	5	117	52.7	0.0	8.0	7.8
South	1 - 5	1	48	26.7	1.7	7.6	5.1
	6 - 10	2	29	38.0	1.8	10.3	9.1
	11 - 20	1	37	43.0	6.4	16.1	8.3
	> 20	2	113	74.3	0.0	9.9	10.4
	All Bldgs.	6	227	74.3	0.0	10.5	9.3
West	1 - 5	1	289	50.1	0.0	11.5	7.7
	6 - 10	1	118	55.6	0.1	6.7	6.0
	11 - 20	3	175	54.7	0.0	8.9	7.6
	> 20	1	19	33.4	0.0	13.1	8.7
	All Bldgs.	6	601	55.6	0.0	9.9	7.7

Government and Private Buildings

(Only those rooms that were randomly selected were used for this table.)

3.5 Influence of Occupant Characteristics

A comparison of the fire and live loads for general and clerical offices for government and private office buildings is given in Figures 10 through 13. These figures were traced directly from histogram plots obtained using the computer plotting routine described in Reference 6. The intervals used to plot the histograms were based on examination of initial plots obtained using standard techniques for determining the number of intervals (12). In view of the small sample size, larger intervals were used. Note that the abscissas for these plots were terminated at a point beyond which the data in any given interval was less than one percent. Consequently, the maximum values do not appear. Cumulative frequency distributions obtained from the histograms are given in Figures 14 and 15.

The distributions in Figures 10 and 11 are positively skewed. The mean fire load for private offices in Figure 11 is slightly higher (approximately seven percent) than that for government offices. The coefficient of variation for the government offices, however, is approximately eight percent larger. The cumulative frequency distributions for the two occupancies in Figure 14 are quite similar and the 99 percent fractiles are almost identical (Government = 24 psf, Private = 22 psf).

For live loads in Figures 12 and 13, the mean value for government offices is approximately ten percent higher than that for private offices. The use of more metal furniture in government offices could account for the live load being greater and the fire load being less than in private offices. Although the differences are small, further examination of the data may provide an explanation. The coefficients of variation for the two occupancies are identical and the cumulative frequency distributions in Figure 15 are quite similar.

The results in Figures 10 through 15 do not indicate any significant differences between the mean fire and live loads in general and clerical offices for government and private occupancy. Further comparisons of the effect of type of occupant on the loads for other room uses and the composition of the fire load (interior finish vs. movable contents) are included in Section 3.6.

The influence of firm type on occupancy duration is shown in Table 23 and Figures 16, 17, and 18. Standard classifications developed to promote uniformity and comparability in the presentation of statistical data (11) were used in establishing the firm types in Table 23. Occupancy duration in this case refers to the length of time a firm occupied the particular office in the buildings surveyed (5). It does not reflect the time period for which the room use (general, clerical, etc.) has remained the same since the firm's space utilization may have changed during this occupancy period. This definition is the same as that used by Mitchell in a survey in England in which occupancy duration data were obtained by consulting telephone directories for firm address changes over a twenty-three year period (8).

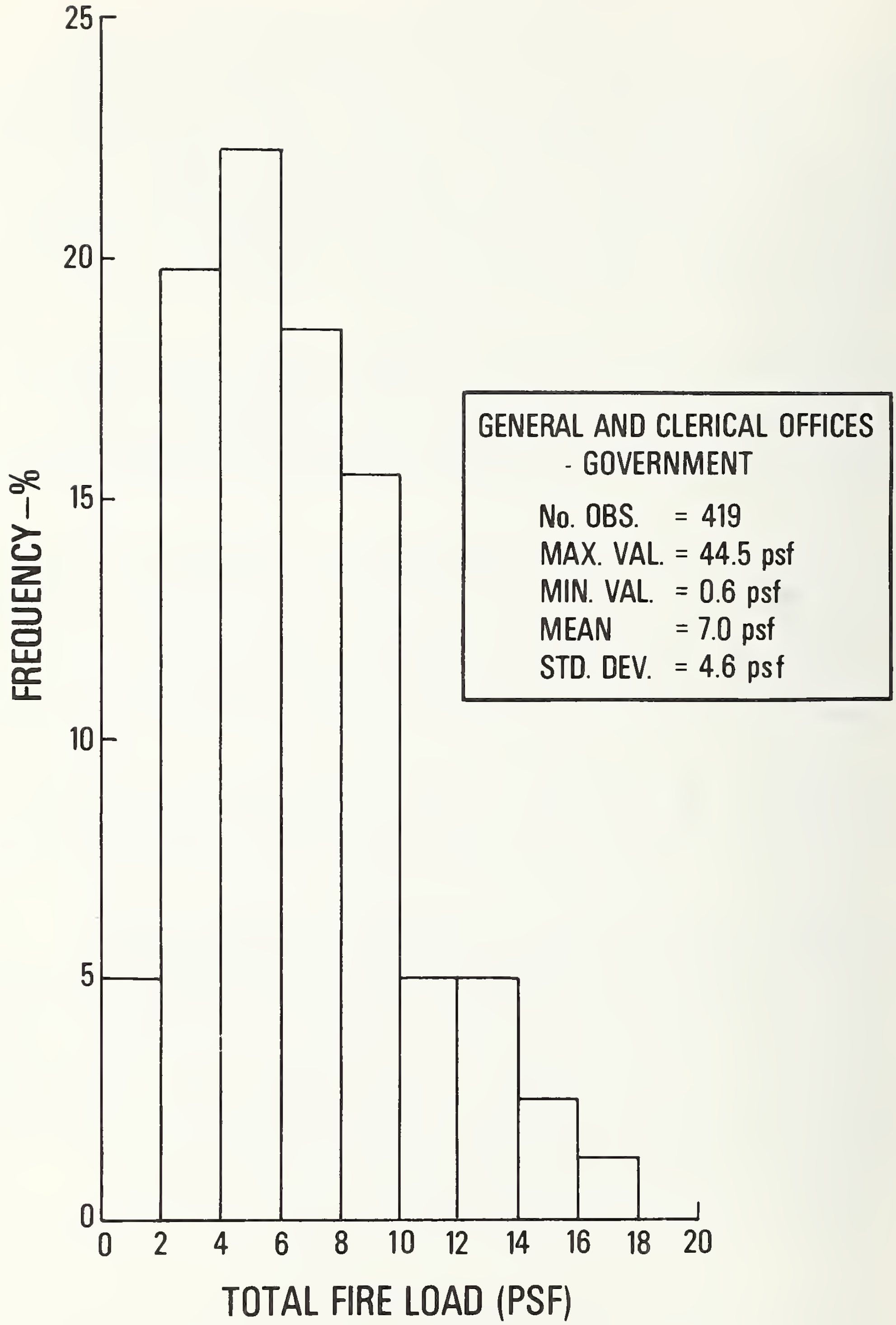


Figure 10 - Frequency Distribution of Room Fire Load Data for Government Office Buildings

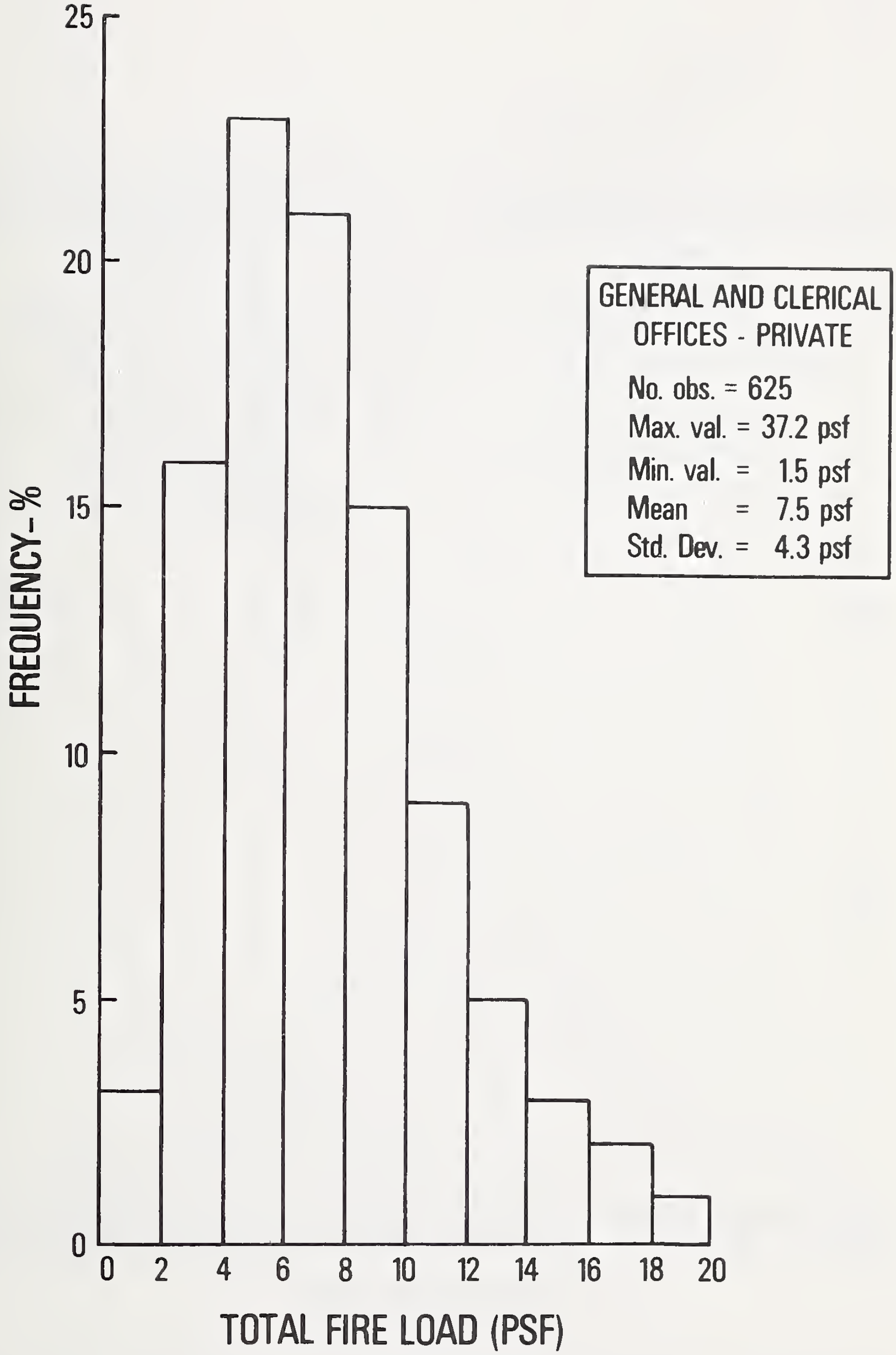


Figure 11 - Frequency Distribution of Room Fire Load Data for Private Office Buildings

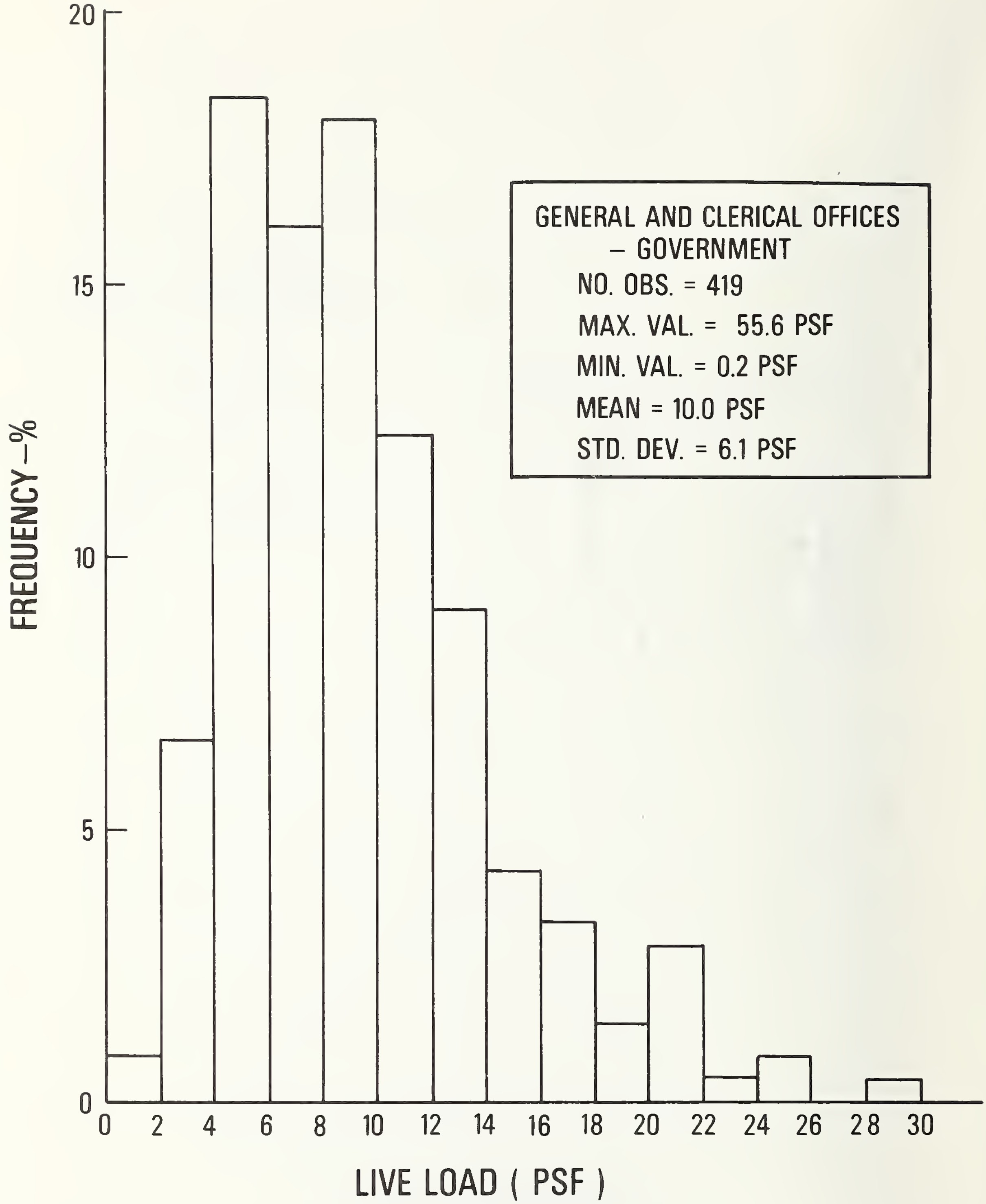


Figure 12 - Frequency Distribution of Room Live Load Data for Government Office Buildings

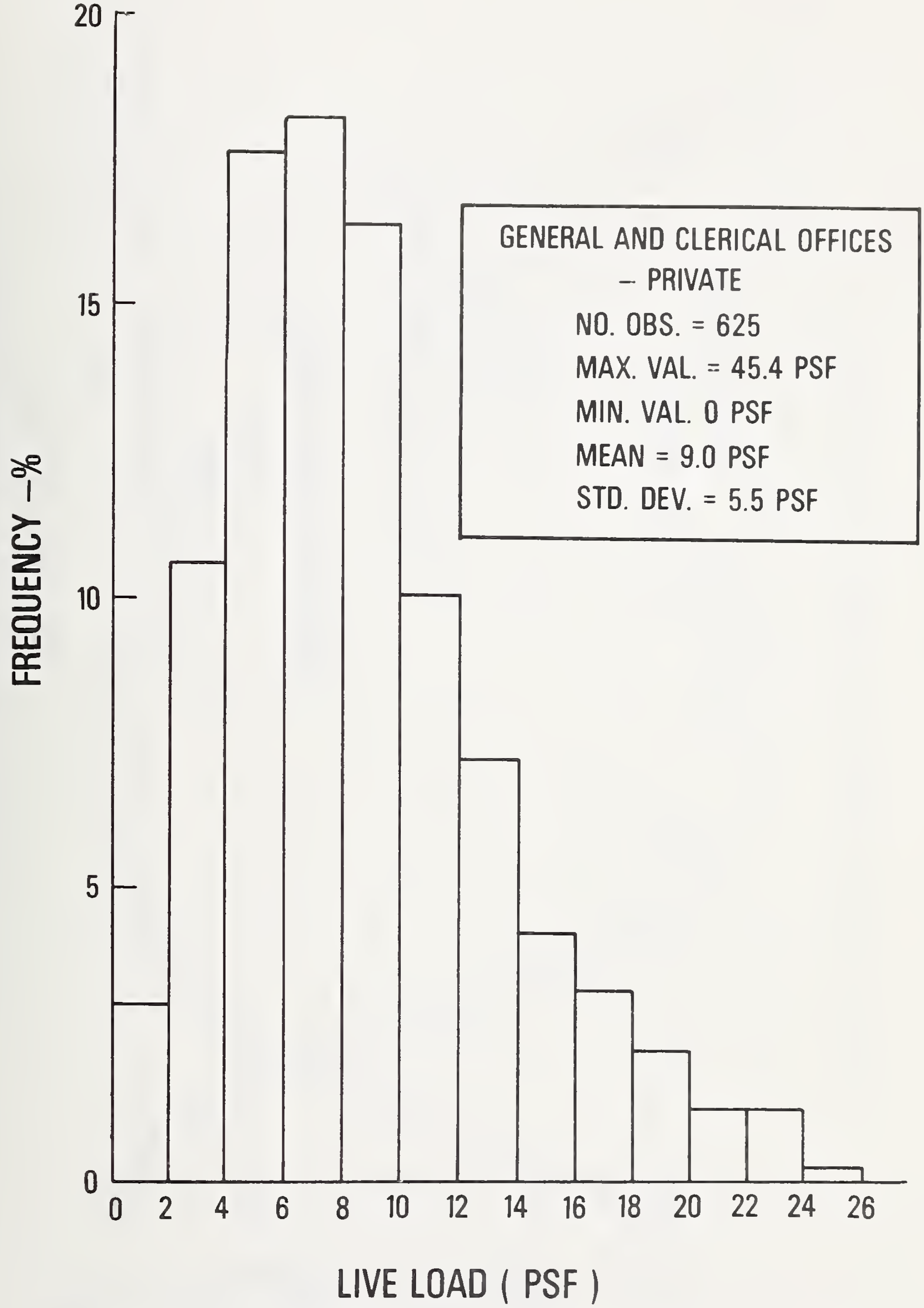


Figure 13 - Frequency Distribution of Room Live Load Data for Private Office Buildings

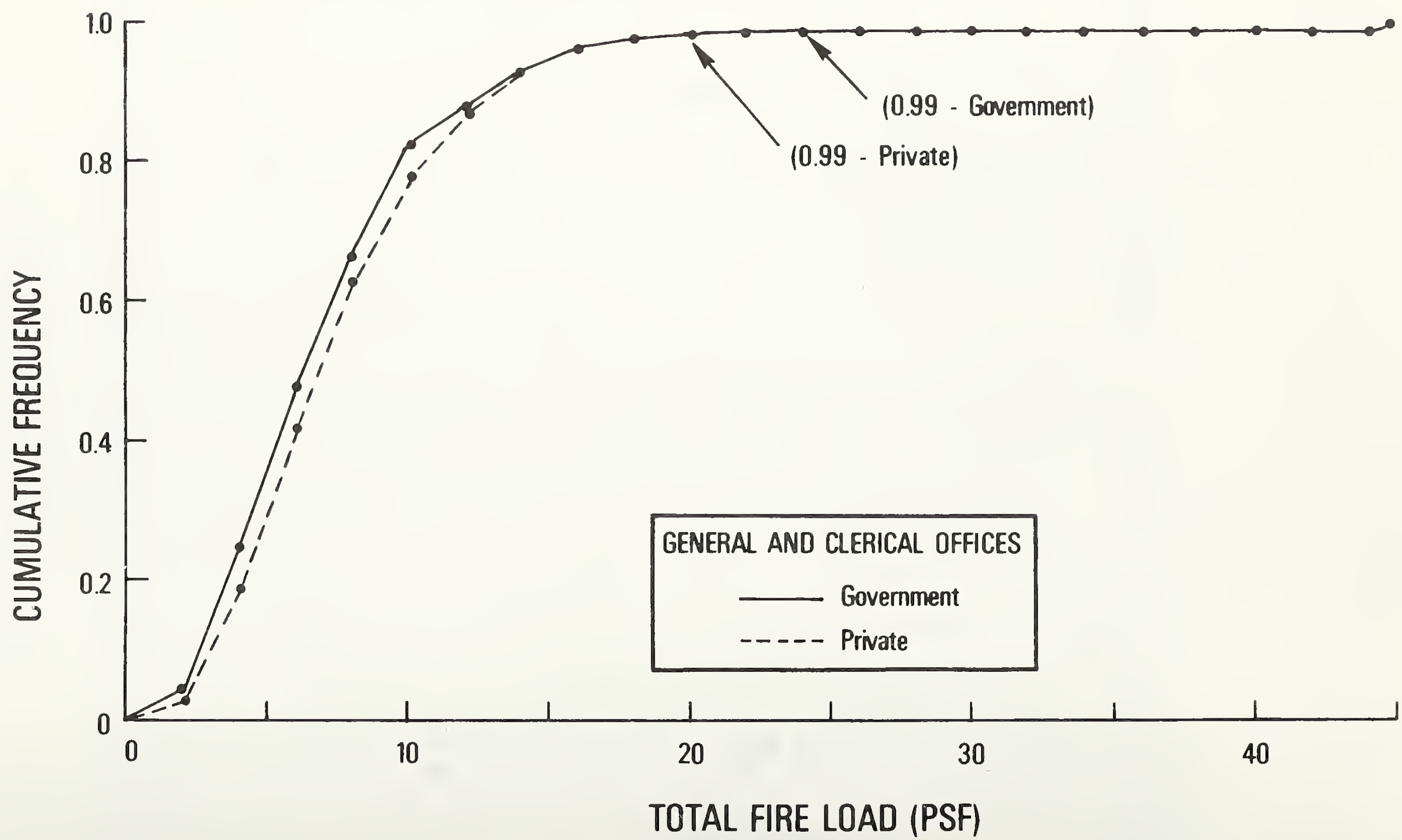


Figure 14 - Cumulative Frequency Distribution for Room Fire Load

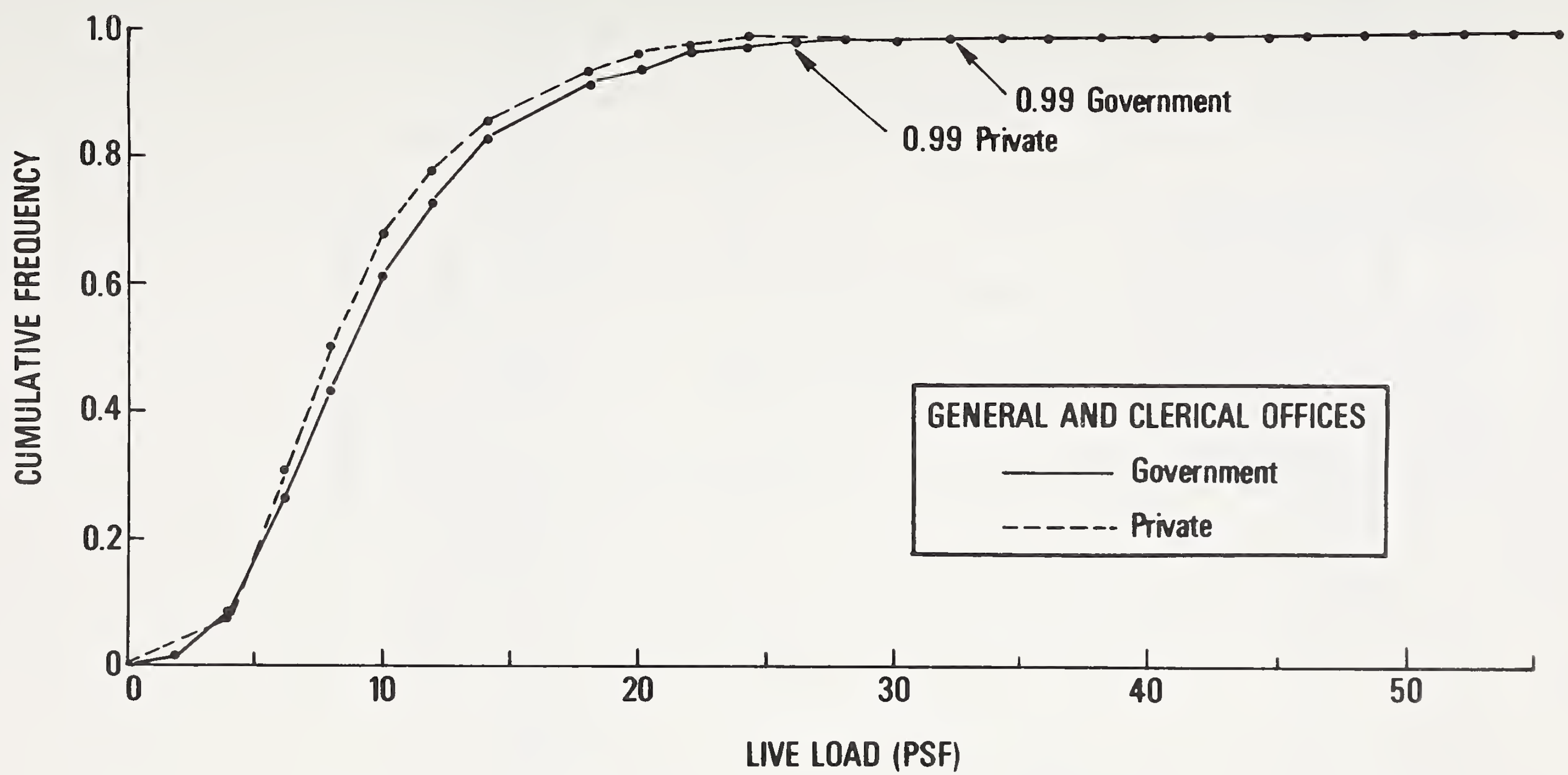


Figure 15 - Cumulative Frequency Distribution for Room Live Load

TABLE 23 INFLUENCE OF FIRM TYPE ON OCCUPANCY DURATION

Firm Type	No. of Firms		Occupancy Duration (Years)	
	Gov't.	Private	Gov't.	Private
Agriculture	0	0	--	--
Mining	0	0	--	--
Construction	0	8	--	7.4, 6.2
Manufacturing	0	29	--	10.1, 7.7
Transportation	1	13	5, -	5.1, 4.0
Trade	0	43	--	7.5, 9.8
Finance	0	105	--	8.6, 10.6
Service	8	206	15.5, 12.1	7.7, 8.1
Public Administration	58	12	7.8, 6.8	7.3, 4.4
Non Classifiable	8	8	6.0, 0	4.8, 3.2
All Firm Types	75	424	8.4, 7.5	7.9, 8.7

*Values listed are sample mean and standard deviation - $\overline{X}$, s

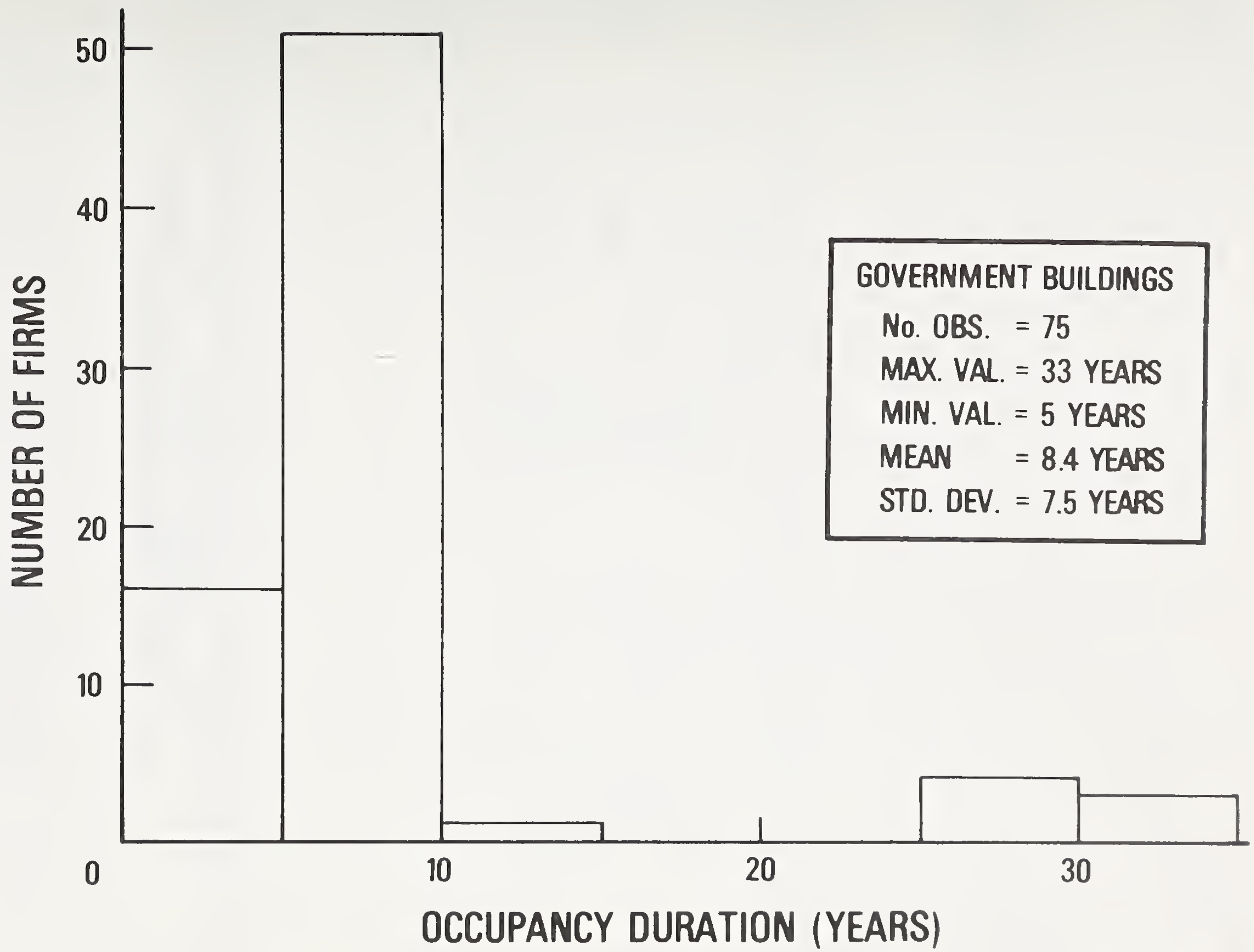


Figure 16 - Frequency Distribution of Occupancy Duration for Government Office Buildings

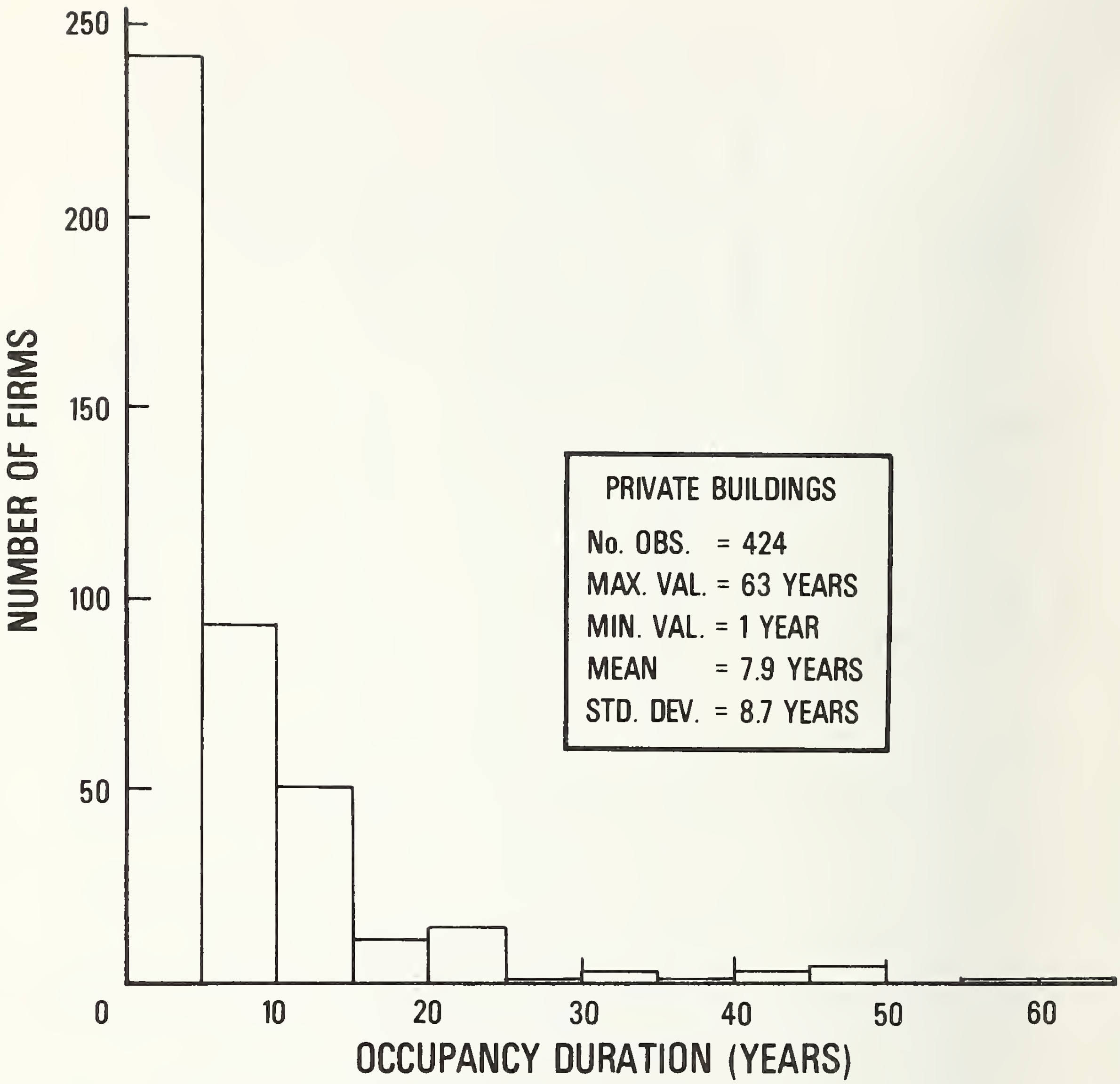


Figure 17 - Frequency Distribution of Occupancy Duration for Private Office Buildings

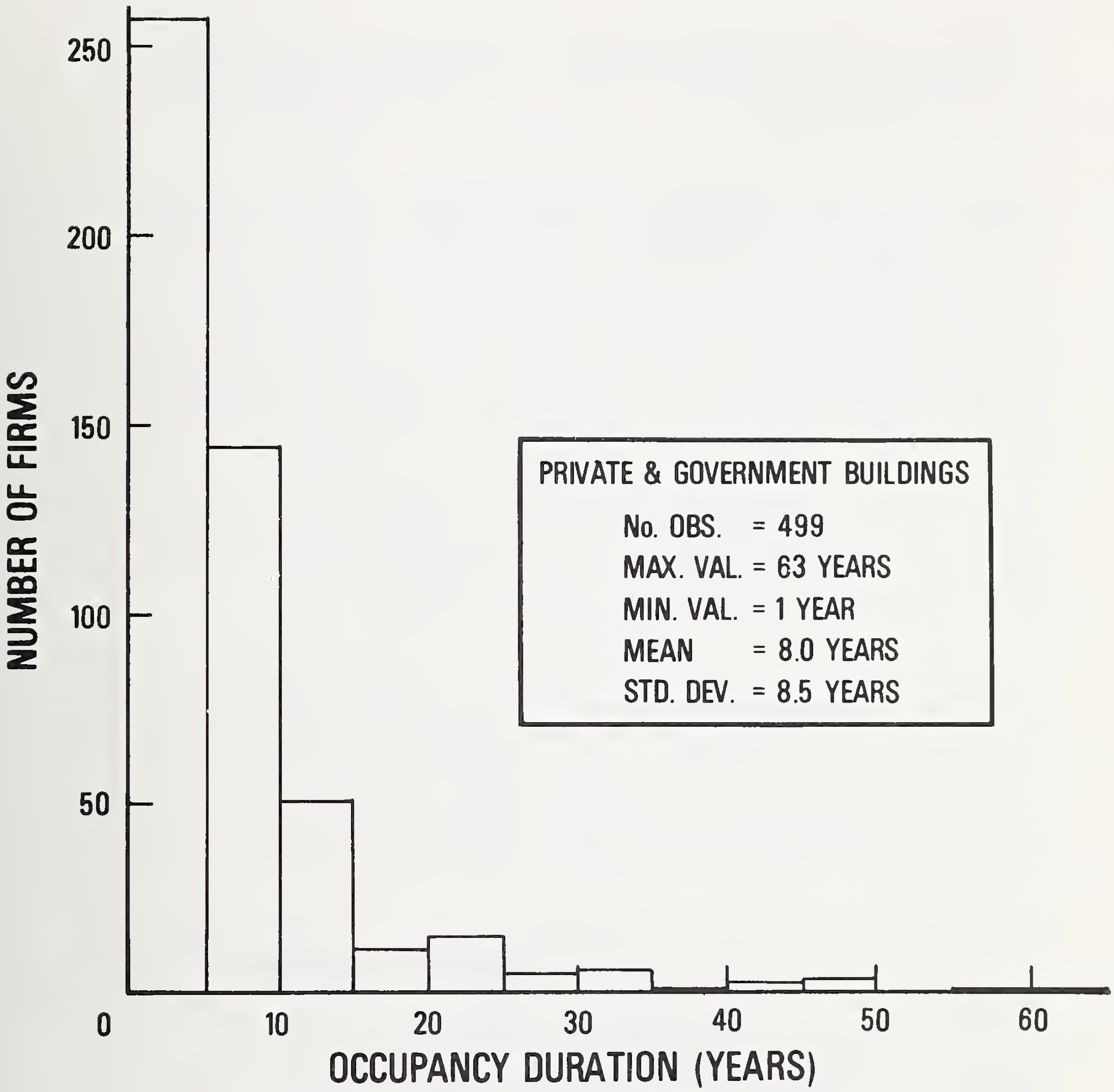


Figure 18 - Frequency Distribution of Occupancy Duration for Government and Private Office Buildings

Data on agriculture and mining firms were not obtained since they were not encountered in the buildings surveyed. For some firm types, the sample size was very small. A majority of the firms in the private sector were service or financial type organizations. Government firms were primarily public administration.

Mean values for occupancy duration varied between firm types. It was somewhat longer for manufacturing firms in the private sector and quite a bit longer for government service organizations. The occupancy durations for a given firm type varied considerably and the standard deviations in Table 23 are quite large in most cases. For private firms, occupancy durations ranged from less than one year to sixty-three years; for government organizations from five years to thirty-three years. The mean value of occupancy duration of 8.4 years for government organizations in Figure 16 was slightly higher than the 7.9 years for private firms in Figure 17. In view of the smaller sample size and the fact that most of the government buildings were relatively new, this difference may be somewhat larger for the entire population.

The mean values of occupancy duration for the government and private buildings and the total sample included in this survey are close to the mean value of 8.8 years obtained by Mitchell. Since Mitchell's results were obtained from modern buildings (less than 20 years old) in downtown London, it appears that occupancy duration is not a function of building age.

Variation of fire and live load magnitude as a function of occupancy duration for 1314 rooms is shown in Figures 19 and 20. The mean value does not change significantly with occupancy duration. The variation or range, however, is considerably larger for the shorter occupancy durations. The sample sizes for the longer durations were very small, however, and collection of additional data could yield similar large variations. Although there is considerable scatter, the data do not indicate any tendency for the loads to increase with time as one might expect. The influence of occupancy duration and firm type as predictors for fire and live load magnitudes is considered in Section 3.8.

Although no attempt was made in this survey to directly monitor load changes with time, data obtained from the NBS Administration Building can be used for this purpose by comparison with data obtained in a survey conducted in 1967 (4). Results from the two surveys are given in Table 24. In comparing these results it should be recognized that the 1967 survey involved direct weighing and the 1974 survey used an inventory procedure. Note that the occupancy duration for the 1974 survey is listed as nine years whereas the age of the building in Table 3 is given as eleven years. Since the building was constructed in 1964 and 1975 was used to compute the ages for the buildings surveyed, the age was considered to be eleven years. The building was not fully occupied until 1965, however, and thus nine years was used for the occupancy duration in Table 24. The 1967 survey was conducted after two years of occupancy and the present survey after nine years. The number of rooms in the two surveys was different since Floors 1, 8, 10, and 11 were not

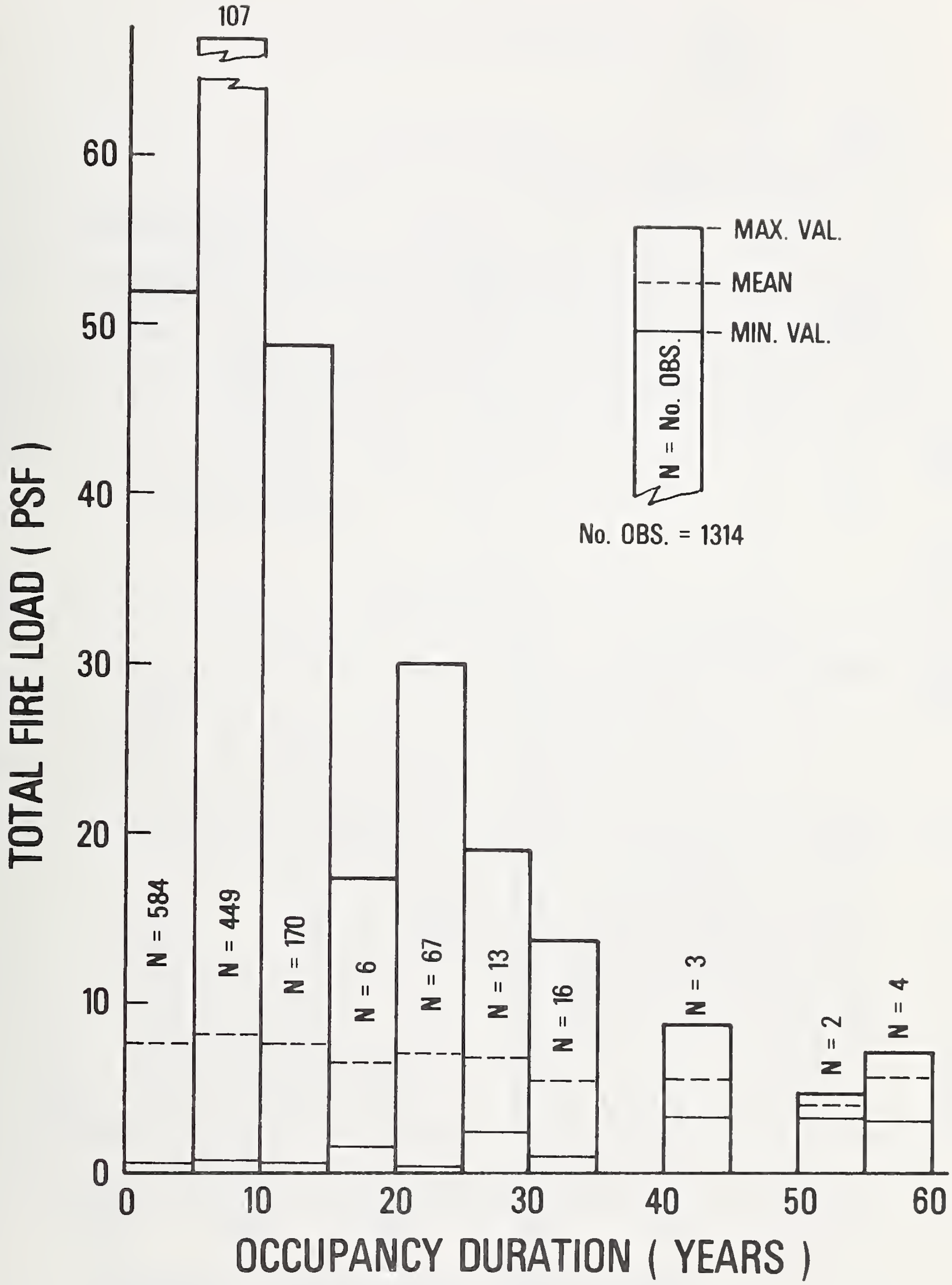


Figure 19 - Variation of Fire Load with Occupancy Duration

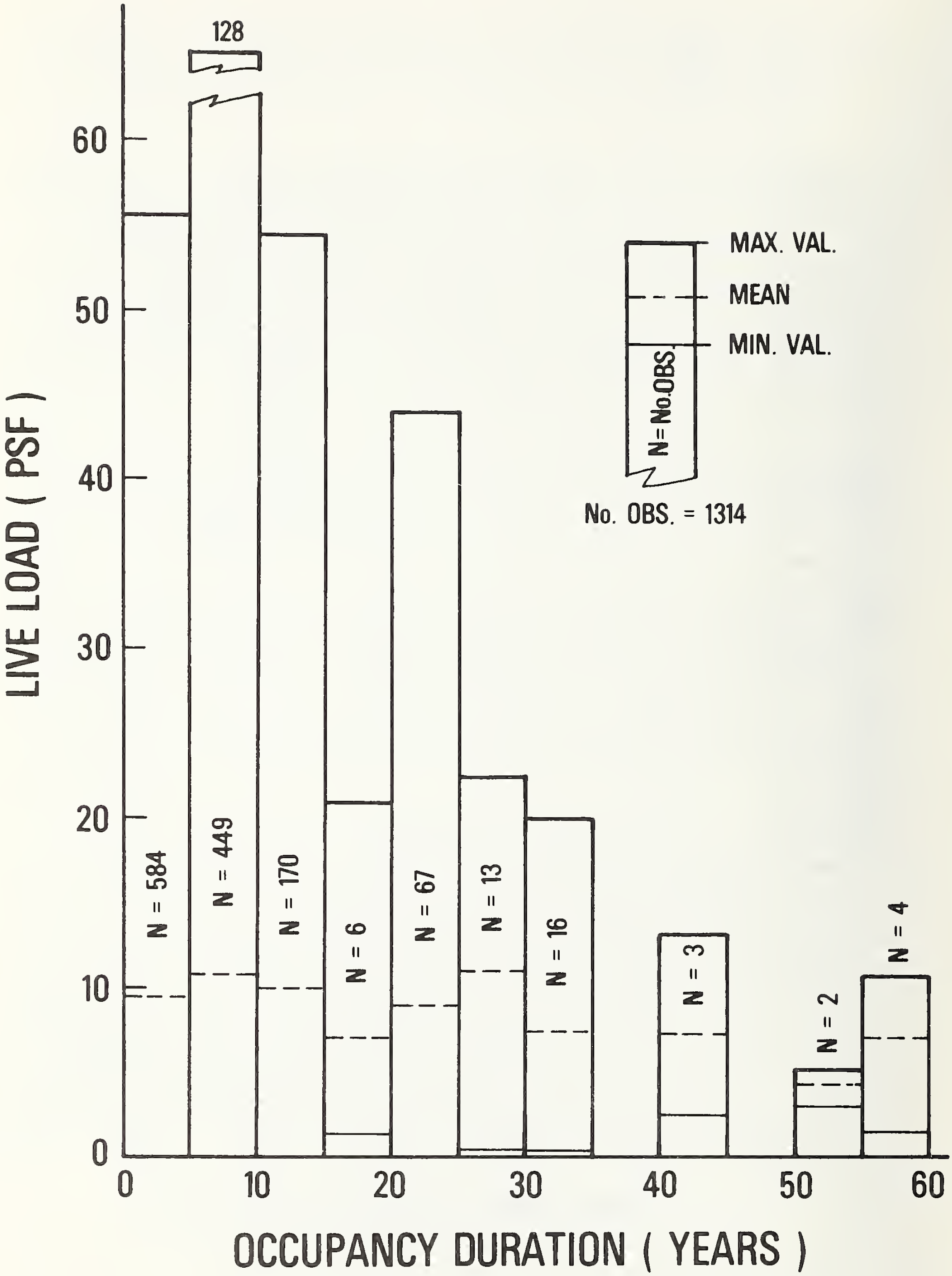


Figure 20 - Variation of Live Load with Occupancy Duration

TABLE 24 INFLUENCE OF TIME ON LOAD MAGNITUDE
(NBS Administration Building)

(a) Room Loads

Survey Date	Occupancy Duration (Years)	No. of Rooms Surveyed	Derated Fire Load (psf)	Live Load (psf)
1967	2	335 (total)	6.3, ---	------
		252 (offices)	6.0, ---	11.9, 5.2
1974	9	149	10.4, 6.4	15.7, 8.1

Values listed are sample mean and standard deviation - $\overline{X}$, s

(b) Floor Loads

Floor No.	1967 Survey			1974 Survey		
	Total Survey Load (lb) (1)	Total Area* (ft^2) (2)	$^{(1)}/_{(2)}$ (psf)	Total Survey Load (lb) (3)	Total Area* (ft^2) (4)	$^{(3)}/_{(4)}$ (psf)
1	65720	11178	5.9	----	--	--
2	----	---	---	----	--	--
3	55217	5859	9.4	79971	6060	13.2
4	88273	5947	14.8	118229	5796	20.4
5	80849	6037	13.4	81939	5815	14.1
6	61853	6040	10.2	95130	6131	15.5
7	110099	5900	18.7	102063	6010	17.0
8	89344	5989	14.9	----	--	--
9	94980	6283	15.1	90191	4650	19.4
10	76861	6059	12.7	----	--	--
11	57310	5996	9.6	----	--	--
12	43027	5532	7.8	52640	6030	8.7

*Room area surveyed exclusive of corridors, lavatories, etc.

included in the present survey. Although various rearrangements of the office space took place during this time, the type of occupancy and general use of the building remained the same.

The results in Table 24(a) indicate that the mean live load increased by 31 percent from 11.9 psf in 1965 to 15.7 psf in 1974. The derated fire load, however, increased by more than 70 percent.

The total live load on each floor is given in Table 24(b). Loads were not determined in either survey for the second floor which is a mechanical equipment floor. Note that the floor numbers correspond to those used in the 1974 survey. Loads for Floors 3 through 12 correspond to values given in Reference 4 for Floors 2 through 11 since the mechanical equipment floor, Floor 2, was not counted in that survey. The floor areas given correspond to the room area surveyed and do not include equipment areas (elevator shafts, telephone closets), lavatories, and corridors. Slight differences exist in these areas for the two surveys due to rearrangement of partitions and measurement errors. The difference in survey area for Floor 9 was due to the fact that two of the larger rooms surveyed in 1974 were discarded due to erroneous data. The total load increased on Floors 3, 4, 5, 6, and 12 and decreased on Floor 7. The largest increase of 54 percent occurred for Floor 6. The total load for the seven floors included in both surveys increased by 16 percent [534,298 lb - 1967 vs. 620,163 - 1974]. The percent increase in the total load is approximately half that for the increase in the mean room live load in pounds per square foot. This may be a result of rearranging some of the load present in 1967, i.e. some of the load may have been moved from room to room to create higher psf loadings in the individual offices. A more detailed study of the data is required to fully explain the differences observed.

The results for the NBS Administration Building indicate a tendency for loads to increase with time in contrast to the data in Figures 19 and 20. It should be noted that the values are within the scatter obtained for the 1 to 5 and 5 to 10 year intervals in Figures 19 and 20. Although the load in an individual building may increase with time, the mean values for a given time interval considering a number of buildings may not change. This may be affected by the occupancy with little or no increase for multiple occupancy buildings in which frequent tenant changes occur as opposed to an increase for single tenant facilities. Obviously the variation of loads with time requires additional study.

3.6 Influence of Room Characteristics

One parameter which may have a significant effect on the composition and magnitude of the loads in offices is room use. Previous surveys, for example, have indicated that file rooms, storage rooms, and libraries are more heavily loaded (4).

Survey data subdivided on the basis of room use are presented in Tables 25 and 26. Data on the fire and live load magnitudes for the seven room use types are included for government and private offices. Since the various room use types occurred with different frequency in the buildings surveyed, the sample sizes vary accordingly. Very few data were obtained in some cases and this must be kept in mind when comparing the results.

Comparing the mean loads for the various room uses in Tables 25 and 26 indicates a definite influence of room use on load magnitude. Both the fire load and live load are larger for file rooms, libraries, and storage areas. Libraries are the most heavily loaded followed in order by file rooms and storage areas. Conference rooms and lobbies have the lowest loads. The trend is the same for both government and private buildings. The live loads for file rooms and libraries in private buildings are quite close but the fire loads in libraries are about 1.5 times those in file rooms. The use of metal cabinets in file rooms may account for this decrease.

The difference between the fire loads and live loads for file rooms is much greater than for libraries. This may be due to the fact that filing cabinets are usually metal whereas wood furniture is more prevalent in libraries.

Although differences exist between the loads in government and private buildings for the various room uses, there is no consistent trend. Whereas the live load for general government offices is greater than that for private offices, the reverse is true for lobbies and conference rooms. A similar trend may be noted for the grand mean live load versus the grand mean fire load.

The results in Tables 25 and 26 indicate that room use has a significant effect on load magnitude. Note that the variability or coefficient of variation for each room use, in most cases, is less than that for all the rooms combined. Room use was included in the load model in Section 3.8. The question of whether this fact should be recognized in specifying design loads for buildings as opposed to using a constant design load throughout a given building is obviously an economic issue. Adopting design loads based on area use within office buildings reduces the flexibility of usage. This may be warranted in certain cases where the owner is the sole occupant and flexibility for rental purposes is not a constraint. The influence of room use should be included in planning future load surveys and will be useful in identifying more heavily loaded rooms.

TABLE 25 INFLUENCE OF ROOM USE ON FIRE LOAD

Room Use	Government Buildings		Private Buildings	
	No. of Rooms	Total Fire Load (psf)	No. of Rooms	Total Fire Load (psf)
General	342	7.3, 4.4	479	7.7, 4.3
Clerical	77	5.8, 5.2	146	6.8, 4.0
Lobby	15	2.6, 1.4	45	5.0, 4.2
Conference	39	4.2, 6.1	57	5.9, 4.6
File	10	17.9, 11.9	20	16.2, 12.9
Storage	35	11.7, 19.2	77	13.2, 11.7
Library	2	30.2, 7.8	10	23.6, 10.8
All Rooms	520	7.3, 7.3	834	8.2, 6.4

Values listed are sample mean and standard deviation - $\overline{X}$, s

(Only those rooms that were randomly selected were used for this table.)

TABLE 26 INFLUENCE OF ROOM USE ON LIVE LOAD

Room Use	Government Buildings		Private Buildings	
	No. of Rooms	Live Load (psf)	No. of Rooms	Live Load (psf)
General	342	9.9, 5.9	479	8.7, 4.9
Clerical	77	10.2, 7.0	146	10.0, 6.9
Lobby	15	2.3, 1.5	45	4.6, 4.8
Conference	39	5.1, 7.0	57	6.1, 5.0
File	10	27.0, 16.3	20	24.4, 19.2
Storage	35	16.5, 23.3	77	15.5, 13.8
Library	2	34.3, 2.8	10	24.9, 9.8
All Rooms	520	10.3, 9.4	834	9.7, 8.1

Values listed are sample mean and standard deviation - $\overline{X}$, s

(Only those rooms that were randomly selected were used for this table.)

The composition of the fire load according to room use and occupancy is given in Tables 27 and 28. The percentages of the total load for interior finish and movable contents are given. Histograms indicating the distributions of this percentage for general and clerical offices are given in Figures 21 and 22. The interior finish load consisted of: the combustible weight (converted to an equivalent weight of cellulose) of the wall materials and coverings such as paneling, paint and wallpaper; ceiling and floor finish materials including carpeting; and trim such as wooden molding on walls, doors, and windows. Furniture, equipment, and other movable items were included as movable contents.

The mean interior finish fire load in psf was almost identical for the various room uses. It was somewhat higher for private buildings than government buildings. Although one might expect the type of finish materials to be different for some types of room use (e.g. file vs. general), this was apparently not the case in this survey. Since the total fire load varies with room use, obviously the percent contribution of the interior finish will vary. Referring to Tables 27 and 28, this percent is greatest for lobbies and least for libraries and file rooms as expected.

Data on the influence of room size on load magnitude are presented in Tables 29 and 30 for the various room use categories and occupancies. The four area size groups used in the tables were arbitrarily selected as representing very small, small, medium, and large size rooms. They were not based on the frequency of occurrence of these areas in office buildings. Note that these data are for rooms and do not represent the load on portions of a floor consisting of two or more rooms (structural bay). In the room selection procedure, rooms were selected on the basis of area being greater or less than 200 ft^2. This may account for the small sample size in some cases and the lack of data in others. It is more likely, however, that the smaller areas are not used for certain types of rooms, e.g. conference rooms would normally be larger than 50 ft^2.

For general and clerical offices in Tables 29 and 30, the mean load decreases with increasing area. There is no apparent trend for the other room use categories which may be due to the small sample size in most cases.

The influence of room size on live load magnitude is further illustrated in Figures 23 through 26. The types of room use and both occupancies were combined for each area size group for the histograms shown. The distributions for all the size groups are positively skewed and do not seem to approach a normal distribution as area increases. The coefficient of variation is quite high for three of the four groups. This may be due to the smaller sample size for these cases. Except for the largest size group, the variability as measured by the coefficient of variation seems to decrease as area increases. Mitchell's data (8) indicated this same trend and his data for various areas showed similar large scatter.

TABLE 27 COMPOSITION OF TOTAL FIRE LOAD
BY ROOM USE FOR GOVERNMENT BUILDINGS

Room Use	No. of Rooms	Total Fire Load* (psf)	Interior Finish Fire Load* (psf)	Percent of Total Fire Load**	
				Interior Finish	Movable Contents
General	342	7.3, 4.4	1.2, 0.4	17	83
Clerical	77	5.8, 5.2	1.2, 0.5	20	80
Lobby	15	2.6, 1.4	1.3, 0.4	50	50
Conference	39	4.2, 6.1	1.2, 0.4	29	71
File	10	17.9, 11.9	1.2, 0.6	7	93
Storage	35	11.7, 19.2	1.2, 0.5	10	90
Library	2	30.2. 7.8	1.0, 0.1	3	97
All Rooms	520	7.3, [illegible].3	1.2, 0.4	17	83

*Values listed are sample mean and standard deviation - $\overline{X}$, s

**Values listed are sample mean

(Only those rooms that were randomly selected were used for this table.)

TABLE 28 COMPOSITION OF TOTAL FIRE LOAD
BY ROOM USE FOR PRIVATE BUILDINGS

Room Use	No. of Rooms	Total Fire Load* (psf)	Interior Finish Fire Load* (psf)	Percent of Total Fire Load**	
				Interior Finish	Movable Contents
General	479	7.7, 4.3	1.9, 0.4	24	76
Clerical	146	6.8, 4.0	1.7, 0.5	25	75
Lobby	45	5.0, 4.2	1.7, 0.6	34	66
Conference	57	5.9, 4.6	1.8, 0.4	30	70
File	20	16.2, 12.9	1.8, 0.6	11	89
Storage	77	13.2, 11.7	1.7, 0.9	13	87
Library	10	23.6, 10.8	1.8, 0.4	8	92
All Rooms	834	8.2, 6.4	1.8, 0.5	22	78

*Values listed are sample mean and standard deviation - $\overline{X}$, s

**Values listed are sample mean

(Only those rooms that were randomly selected were used for this table.)

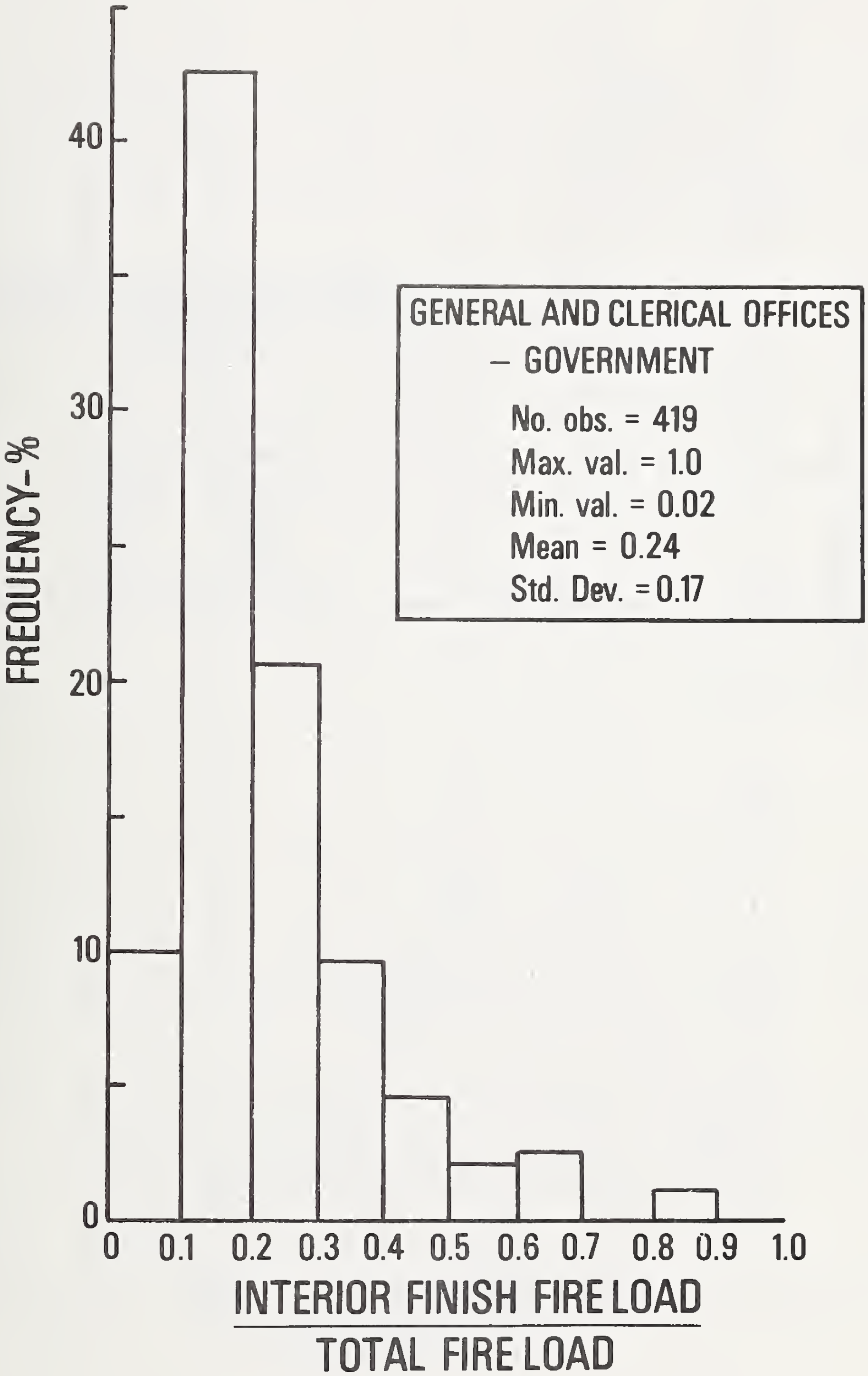


Figure 21 - Percentage of Interior Finish Fire Load - Government Offices

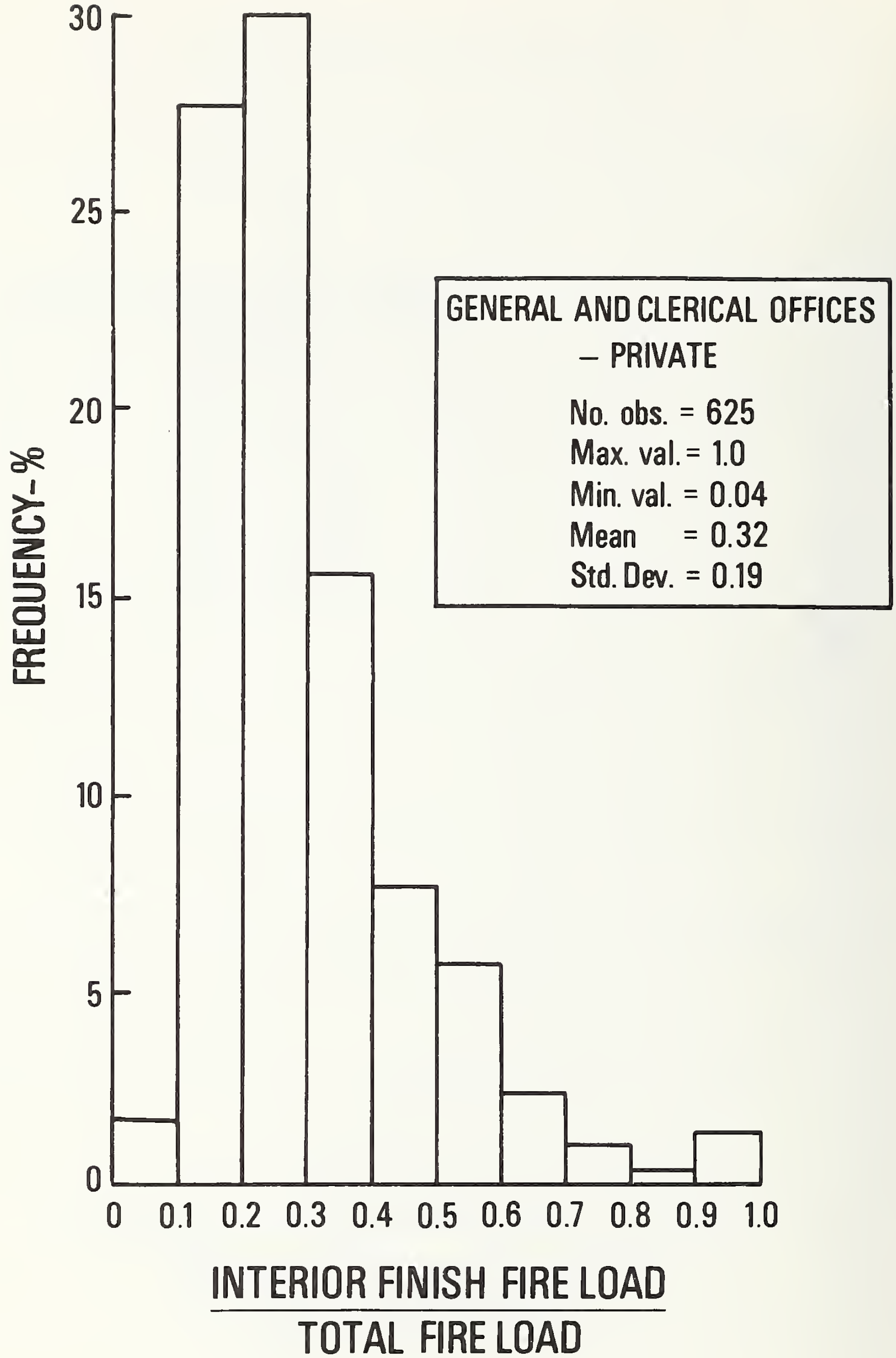


Figure 22 - Percentage of Interior Finish Fire Load - Private Offices

TABLE 29 INFLUENCE OF ROOM SIZE ON FIRE LOAD

Room Use	Area (ft^2)	Government Buildings				Private Buildings			
		No. of Rooms	Total Fire Load (psf)			No. of Rooms	Total Fire Load (psf)		
			Mean	Std. Dev.	Max. Val.		Mean	Std. Dev.	Max. Val.
General	≤ 50	2	30.3	20.2	44.5	3	17.4	17.5	37.2
	< 50 - ≤100	11	7.3	3.1	15.4	107	9.1	4.7	22.5
	<100 - ≤300	294	7.4	4.0	22.1	331	7.4	3.8	28.6
	>300	35	5.3	2.1	10.5	38	6.3	4.3	23.9
Clerical	≤ 50	0	--	--	--	3	10.5	3.7	13.6
	< 50 - ≤100	4	11.3	11.7	27.0	21	10.1	5.9	24.1
	<100 - ≤300	36	6.2	5.6	31.3	78	6.6	3.2	14.1
	>300	37	4.8	3.3	15.9	44	5.3	3.2	15.0
Lobby	≤ 50	0	--	--	--	1	--	--	2.6
	< 50 - ≤100	2	2.1	0.7	2.6	4	4.1	2.9	7.8
	<100 - ≤300	8	2.5	1.5	4.1	29	6.1	4.6	23.6
	>300	5	2.8	1.7	4.6	11	2.7	2.4	7.5
Conference	≤ 50	0	--	--	--	0	--	--	--
	< 50 - ≤100	0	--	--	--	3	7.3	2.9	9.4
	<100 - ≤300	18	3.6	1.5	6.3	45	6.3	4.9	28.1
	>300	21	4.8	8.3	40.3	9	3.3	1.0	4.4
File	≤ 50	0	--	--	--	2	39.0	8.9	45.3
	< 50 - ≤100	0	--	--	--	10	15.3	13.0	48.5
	<100 - ≤300	5	17.7	8.1	22.3	5	9.3	5.1	22.0
	>300	5	18.0	15.9	41.8	3	4.9	0.5	5.2
Storage	≤ 50	3	1.4	1.2	2.0	27	13.8	12.6	51.8
	< 50 - ≤100	6	23.8	41.8	106.6	18	13.3	12.4	35.1
	<100 - ≤300	16	7.1	6.3	22.3	26	11.9	11.3	46.6
	>300	10	14.8	12.9	43.4	6	7.9	9.1	30.4
Library	≤ 50	0	--	--	--	0	--	--	--
	< 50 - ≤100	0	--	--	--	2	17.3	0	17.3
	<100 - ≤300	1	--	--	24.7	7	24.5	12.4	39.9
	>300	1	--	--	35.7	1	--	--	29.6

(Only those rooms that were randomly selected are used for this table)

TABLE 30 INFLUENCE OF ROOM SIZE ON LIVE LOAD

Room Use	Area (ft ^{2})	Government Buildings				Private Buildings			
		No. of Rooms	Live Load (psf)			No. of Rooms	Live Load (psf)		
			Mean	Std. Dev.	Max. Val.		Mean	Std. Dev.	Max. Val.
General	≤ 50	2	40.4	21.5	55.6	3	25.2	17.7	45.4
	< 50 - ≤100	11	10.9	2.4	16.5	107	11.0	5.4	25.7
	<100 - ≤300	294	10.0	5.5	35.2	331	7.9	4.0	33.4
	>300	35	7.0	3.1	14.2	38	7.6	5.4	24.9
Clerical	≤ 50	0	--	--	--	3	14.5	3.7	17.7
	< 50 - ≤100	4	15.4	12.4	31.0	21	16.1	9.6	38.5
	<100 - ≤300	36	10.1	7.1	41.3	78	9.4	5.7	23.4
	>300	37	9.8	6.1	28.5	44	7.9	6.0	23.4
Lobby	≤ 50	0	--	--	--	1	--	--	0.0
	< 50 - ≤100	2	1.1	1.1	1.8	4	3.1	3.8	8.6
	<100 - ≤300	8	2.2	1.3	4.8	29	5.6	5.3	25.9
	>300	5	3.0	1.7	5.7	11	2.8	2.8	7.4
Conference	≤ 50	0	--	--	--	0	--	--	--
	< 50 - ≤100	0	--	--	--	3	6.7	0.3	7.0
	<100 - ≤300	18	4.7	2.9	14.4	45	6.5	5.4	30.8
	>300	21	5.5	9.2	44.7	9	3.8	2.7	10.6
File	≤ 50	0	--	--	--	2	60.0	20.2	74.3
	< 50 - ≤100	0	--	--	--	10	23.2	18.2	54.7
	<100 - ≤300	5	29.4	7.8	43.0	5	22.1	8.2	31.0
	>300	5	24.6	22.9	62.7	3	8.4	2.0	10.0
Storage	≤ 50	3	3.3	2.9	5.3	27	14.3	13.1	49.6
	< 50 - ≤100	6	31.9	49.2	127.7	18	16.1	15.2	44.9
	<100 - ≤300	16	11.0	8.1	29.8	26	15.4	14.0	52.7
	>300	10	20.0	17.6	52.1	6	20.0	14.1	44.6
Library	≤ 50	0	--	--	--	0	--	--	--
	< 50 - ≤100	0	--	--	--	2	17.3	3.1	19.5
	<100 - ≤300	1	--	--	32.3	7	26.3	10.8	38.0
	>300	1	--	--	36.3	1	--	--	30.2

(Only those rooms that were randomly selected are used for this table.)

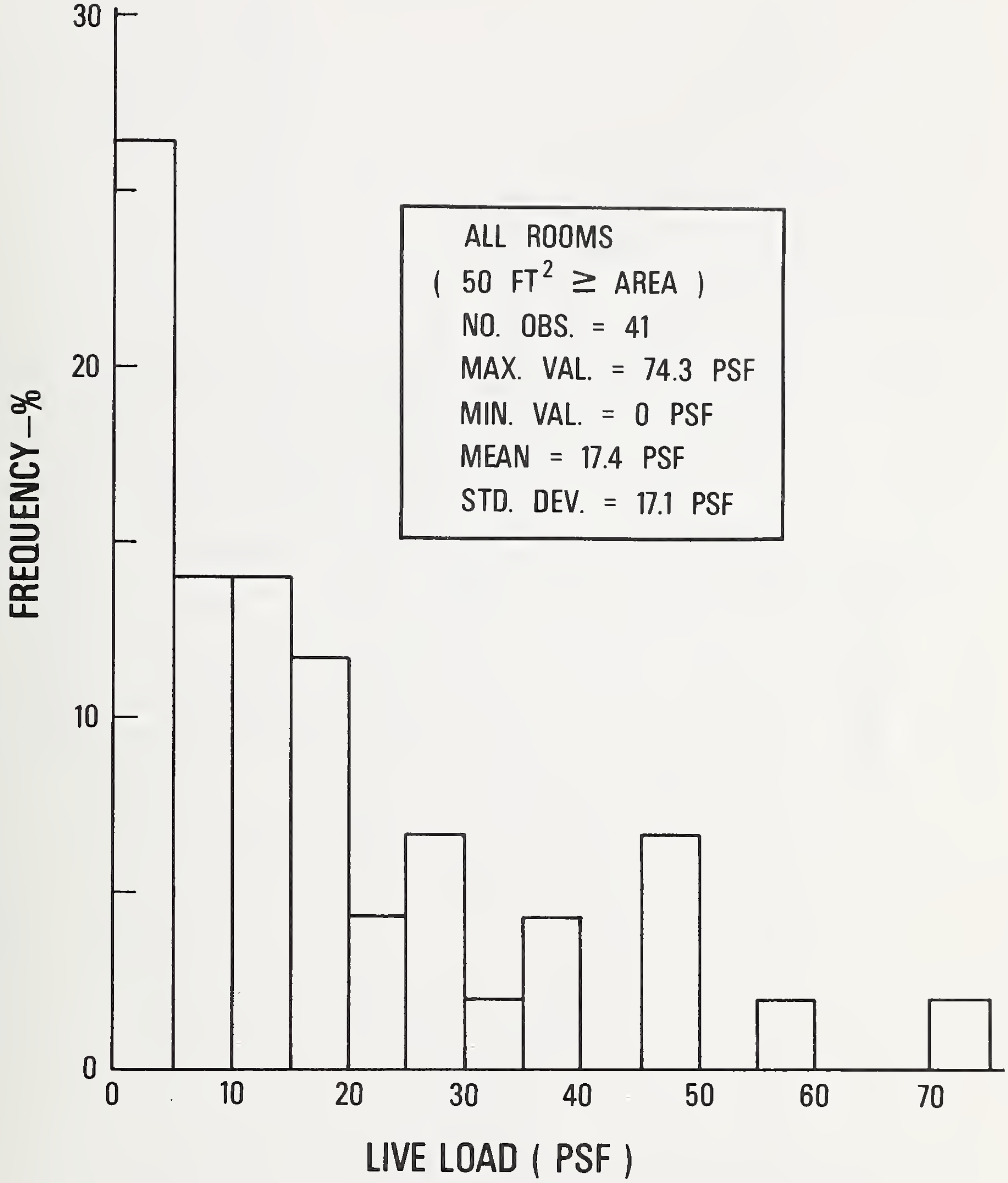


Figure 23 - Load Intensity versus Area of Room - Area ≤ 50 ft^2

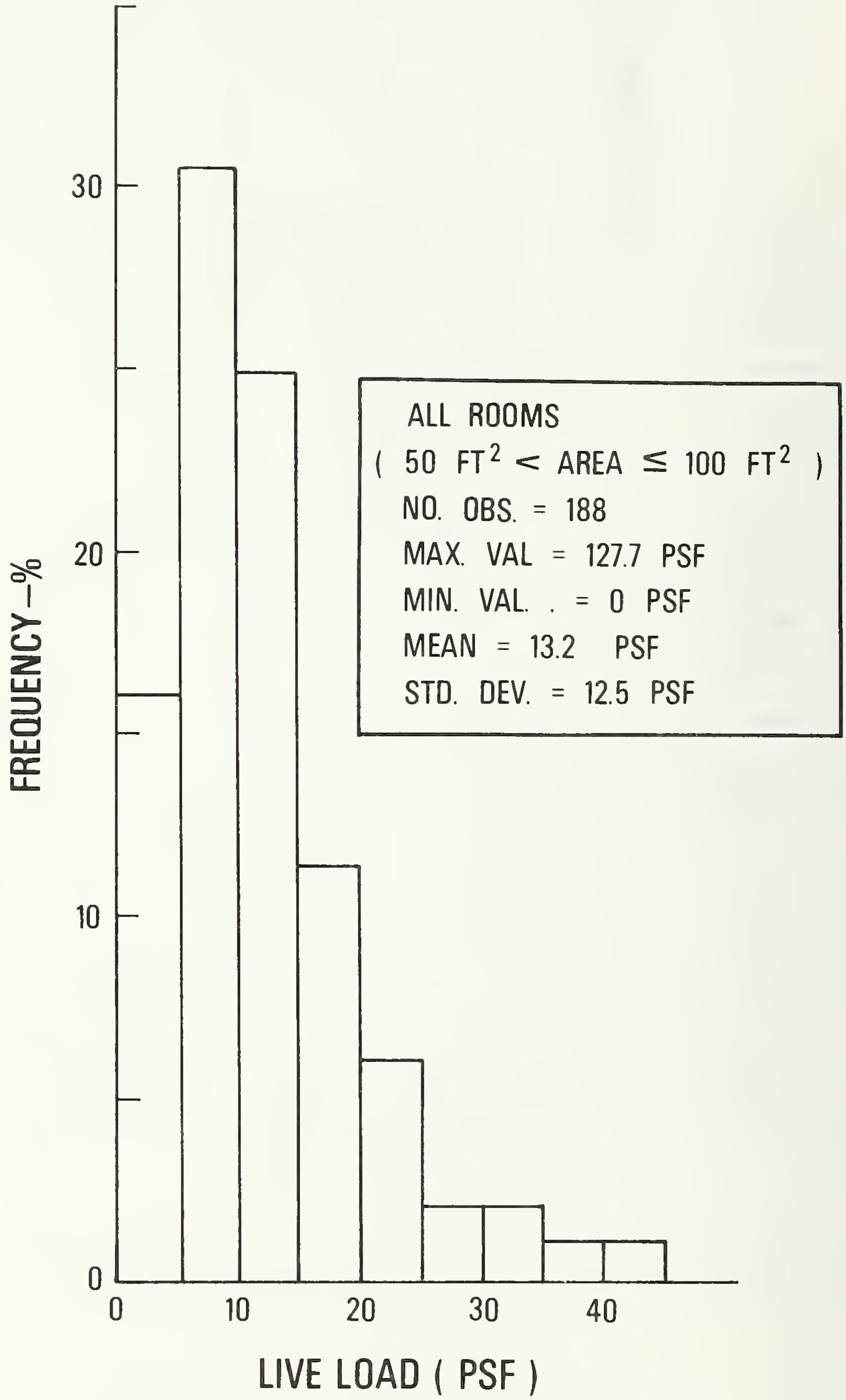


Figure 24 - Load Intensity versus Area of Room - 50ft^2 < Area $\leq$ 100 ft^2

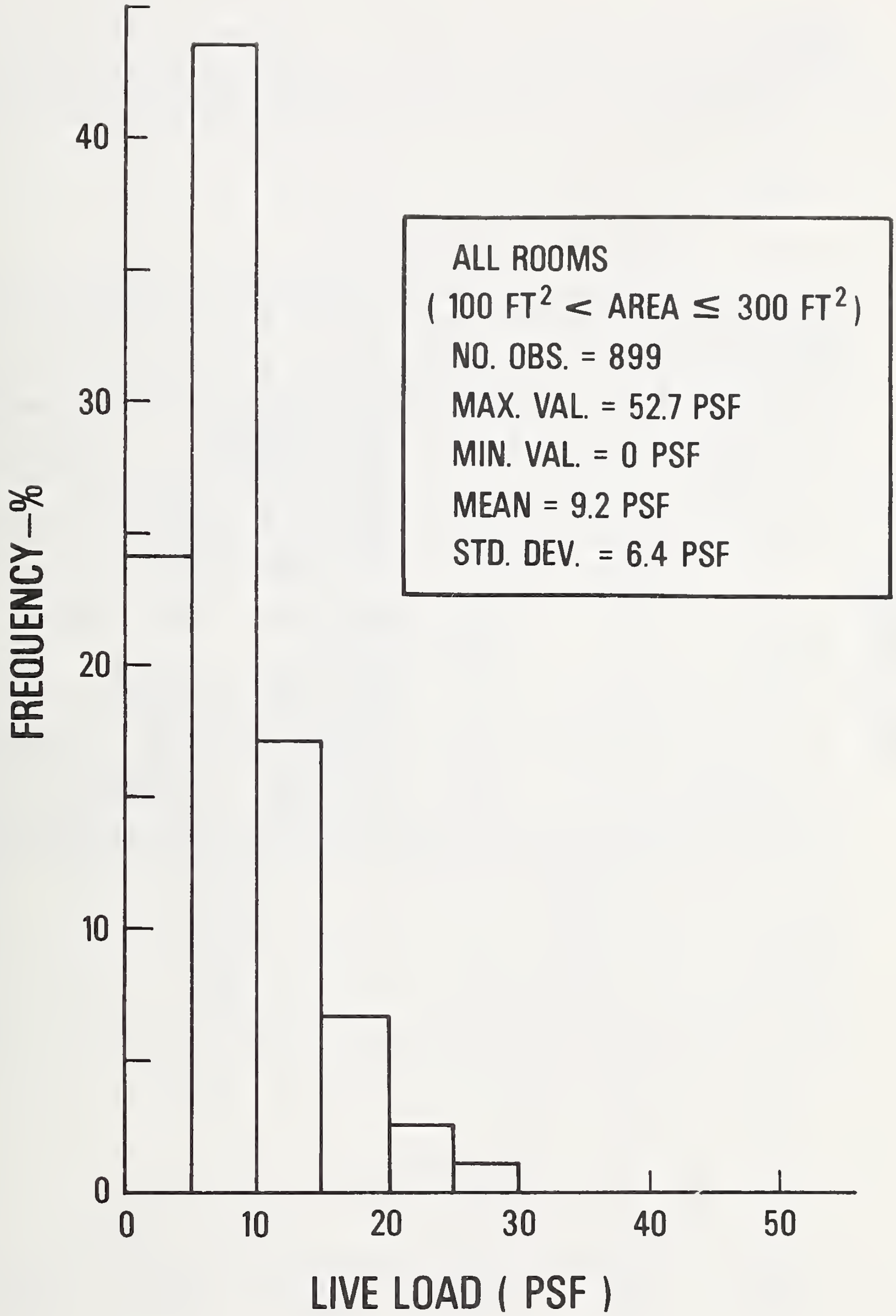


Figure 25 - Load Intensity versus Area of Room - 100 ft^2 < Area $\leq$ 300 ft^2

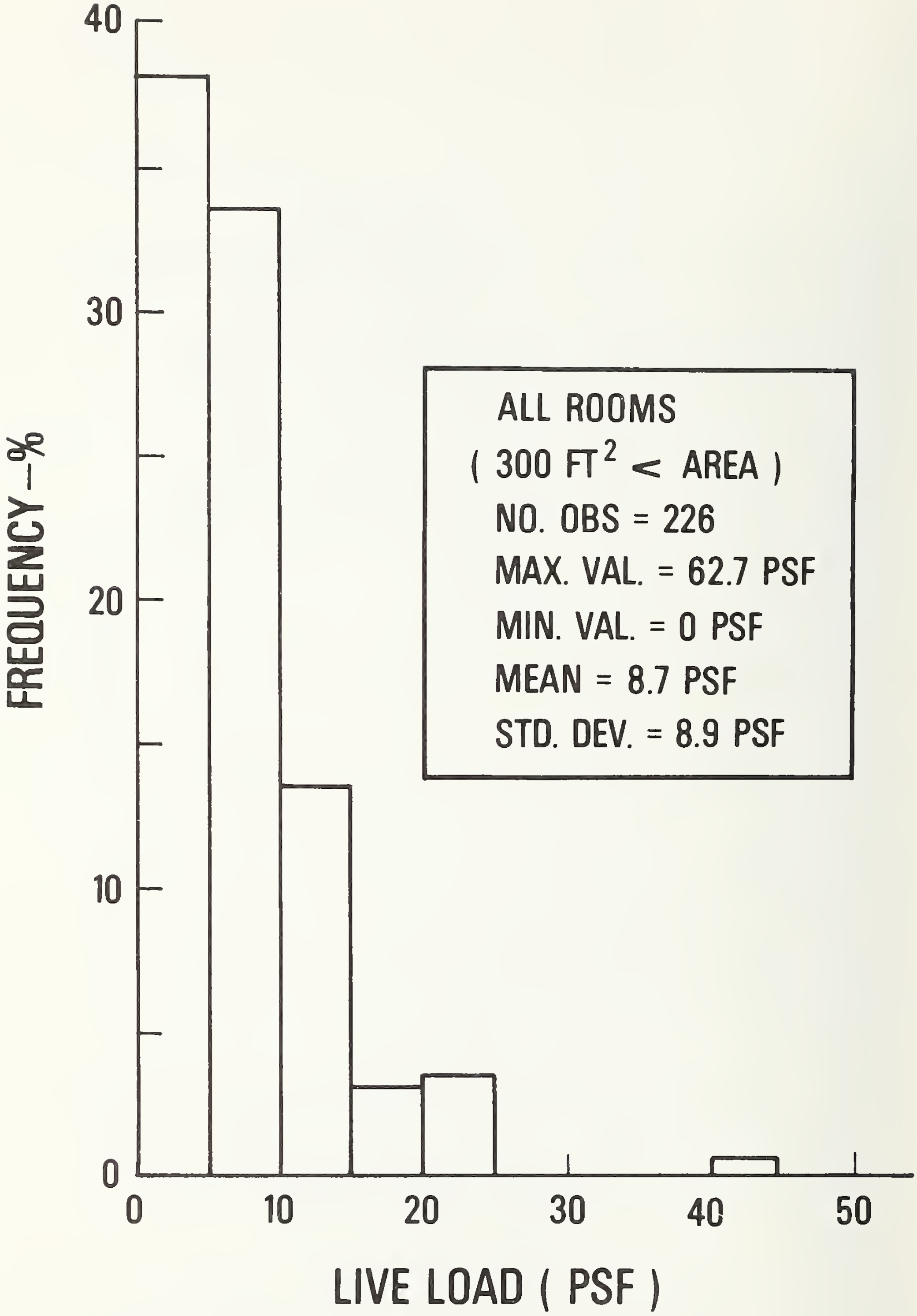


Figure 26 - Load Intensity versus Area of Room - 300 ft^2 < Area

The data in Figures 23 through 26 indicate that the mean load decreases significantly as area increases. The mean for areas greater than 300 ft^2, for example, is only fifty percent of that for areas less than 50 ft^2. This decrease is considerably different from that observed by Mitchell. This is apparent from the following comparison:

Present Survey

Area Range (ft^2)	No. Obs.	Mean Live Load (psf)	Std. Dev. (psf)	Coeff. Var.	99% Fractile* (psf)
0- 50	41	17.4	17.4	1.00	74.3
50-100	188	13.2	12.5	0.95	127.7
100-300	899	9.2	6.4	0.70	33.4
>300	226	8.7	8.9	1.02	52.1

* Fractile values obtained directly from ordered data.

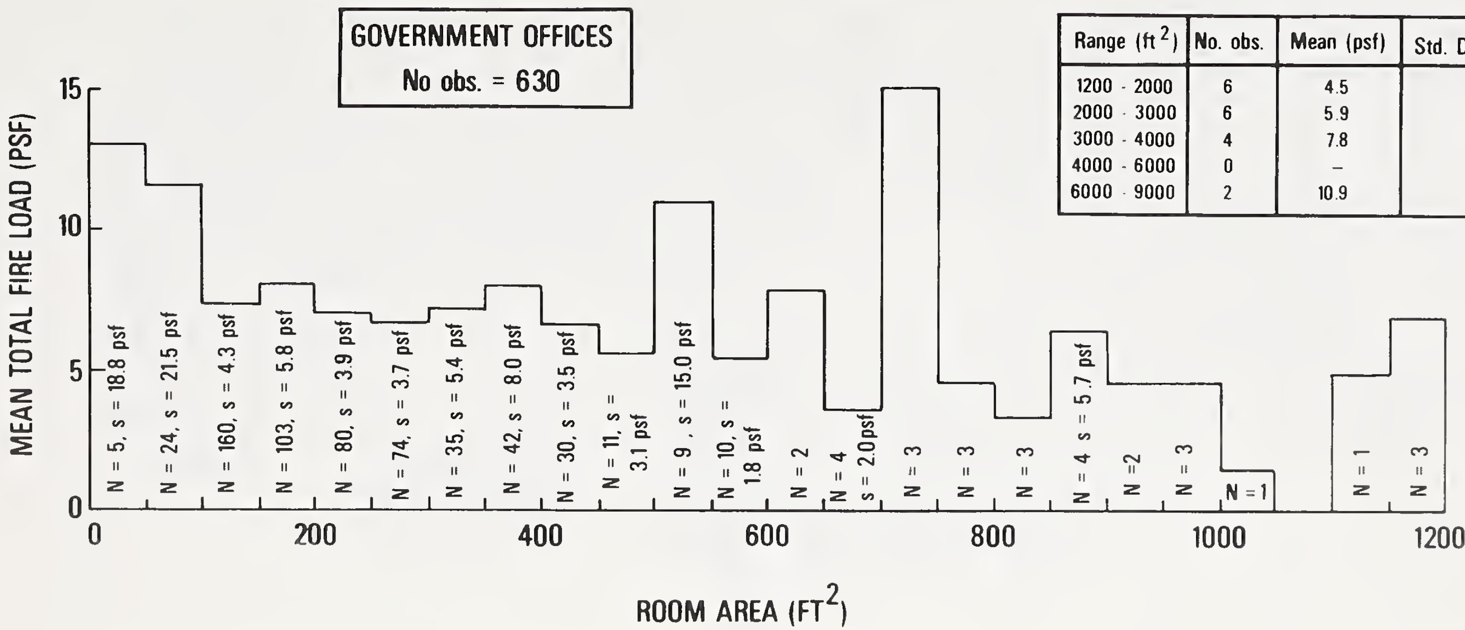
Mitchell's Survey
(Reference 8)

Mean Notional Bay Area (ft^2)	No. Calc.	Mean Live Load (psf)	Std. Dev. (psf)	Coeff. Var.	99% Fractile (psf)
25.3	8840	13.8	13.5	0.98	62
56	14290	13.4	11.0	0.82	52
151	20442	13.0	8.9	0.68	44
336	14283	12.8	7.2	0.56	37
624	6511	12.3	6.3	0.51	32
1197	1885	12.2	5.5	0.45	30
2069	1152	11.8	4.5	0.38	25

It is important to note, however, that the basis used to obtain the loads presented herein was different from that used by Mitchell. Mitchell included the weight of people and assumed certain loads for some areas (corridors, stairways, lavatories, etc.) whereas this was not done in this survey. Also, Mitchell obtained loads per unit area using portions of a floor and subdividing these portions into rectangular bays (notional bays) of varying area and aspect ratio. These notional bay areas did not necessarily coincide with the partitions and consequently, Mitchell's values are not loads per unit area for a room.

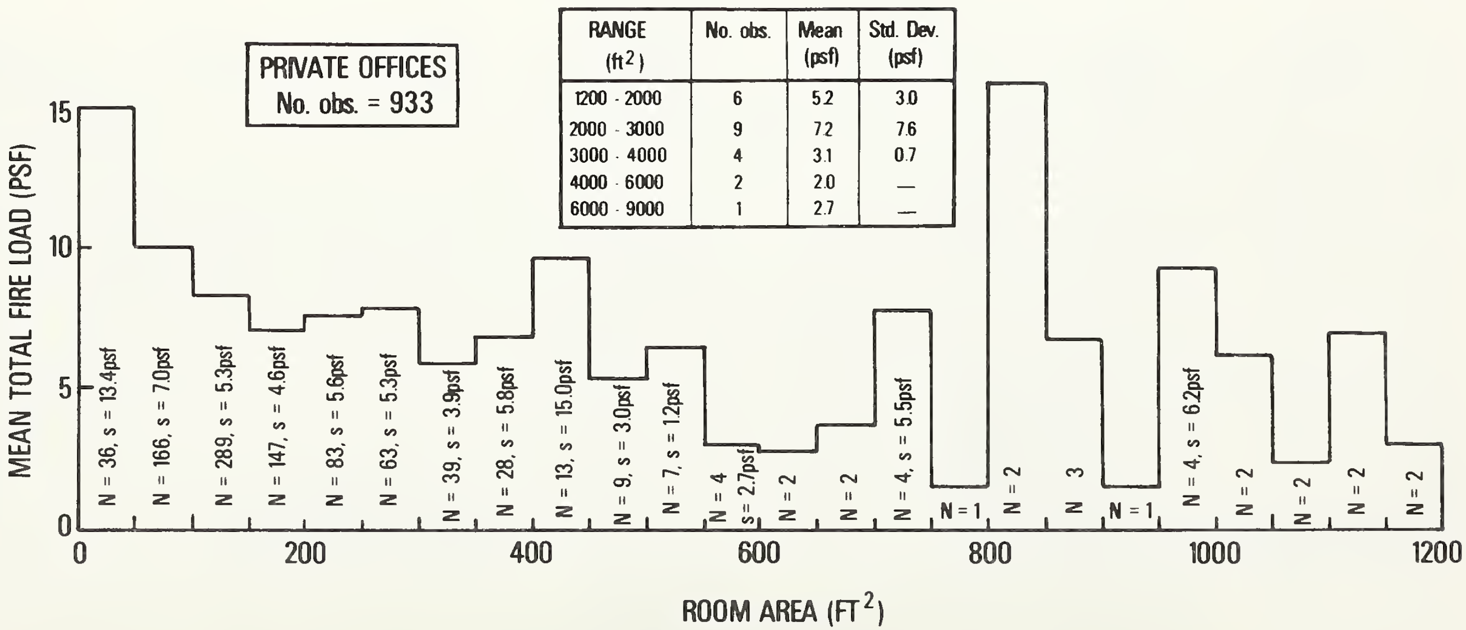
The decrease in mean live load with increasing area is much greater for room loads than for the notional bays. This is probably due to the effect of the notional bay concept unless significant differences existed between the two survey samples. For the smaller notional bay sizes, for example, some of the bays would consist primarily of small heavily loaded rooms while others would be pieces of larger more lightly loaded rooms. The overall mean, therefore, would be less than that for the small rooms which is the case for the data given. Similarly, for large notional bays some of the bays would consist of lightly loaded large rooms whereas others would consist of several smaller more heavily loaded rooms. The overall mean would be larger than that for the large rooms which the data above indicate. For the 99% fractiles, the notional bay values are less than the room values. This may be due to the considerable difference in sample size or the survey samples themselves. Except for the large rooms, the coefficients of variation for the room loads and notional bay loads are about the same and follow the same trend, i.e. decrease as area increases.

The relationship between mean load and room area is also shown in Figures 27 through 30. Here room area intervals of 50 ft^2 were used as opposed to the four groups in Figures 23 through 26. The data in these figures seem to follow the same trend noted previously, i.e. the mean load decreases with increasing room area. In view of the apparent influence of room area on load magnitude, this parameter was included in developing the load models in Section 3.8.



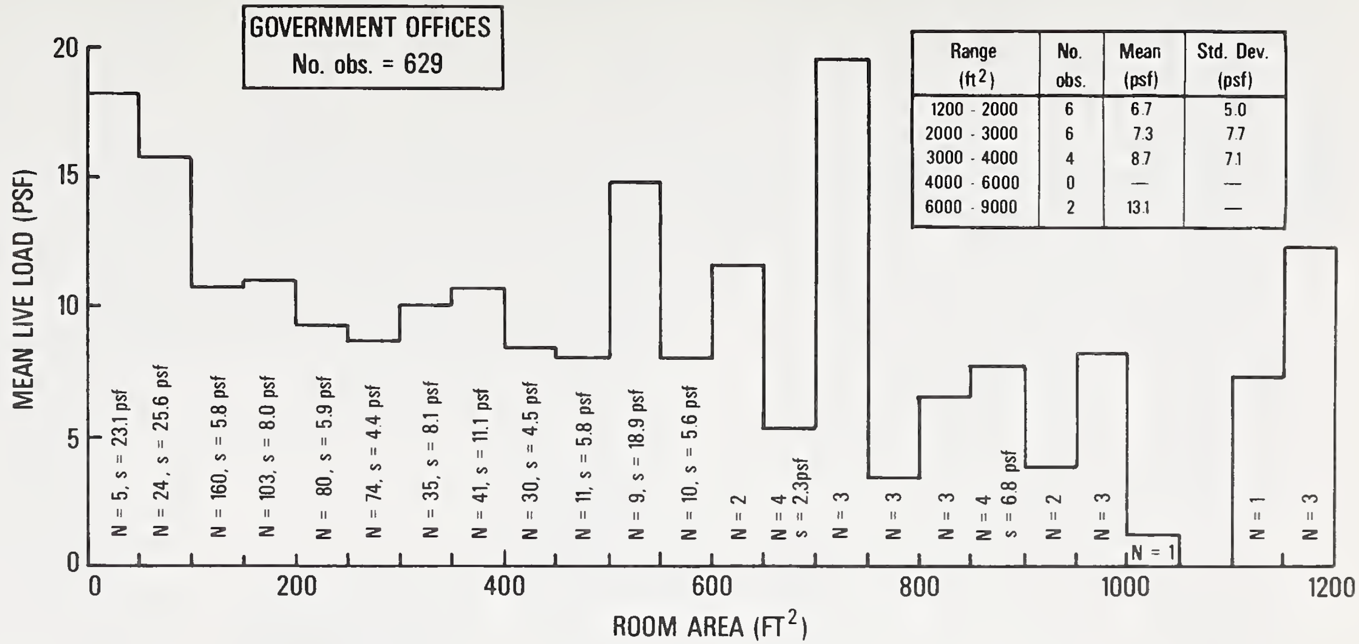
Range (ft^2)	No. obs.	Mean (psf)	Std. Dev. (psf)
1200 - 2000	6	4.5	4.0
2000 - 3000	6	5.9	8.1
3000 - 4000	4	7.8	7.8
4000 - 6000	0	–	–
6000 - 9000	2	10.9	–

Figure 27 - Fire Load versus Room Area - Government Offices



RANGE (ft^2)	No. obs.	Mean (psf)	Std. Dev. (psf)
1200 - 2000	6	5.2	3.0
2000 - 3000	9	7.2	7.6
3000 - 4000	4	3.1	0.7
4000 - 6000	2	2.0	—
6000 - 9000	1	2.7	—

Figure 28 - Fire Load versus Room Area - Private Offices



Range (ft^2)	No. obs.	Mean (psf)	Std. Dev. (psf)
1200 - 2000	6	6.7	5.0
2000 - 3000	6	7.3	7.7
3000 - 4000	4	8.7	7.1
4000 - 6000	0	—	—
6000 - 9000	2	13.1	—

Figure 29 - Live Load versus Room Area - Government Offices

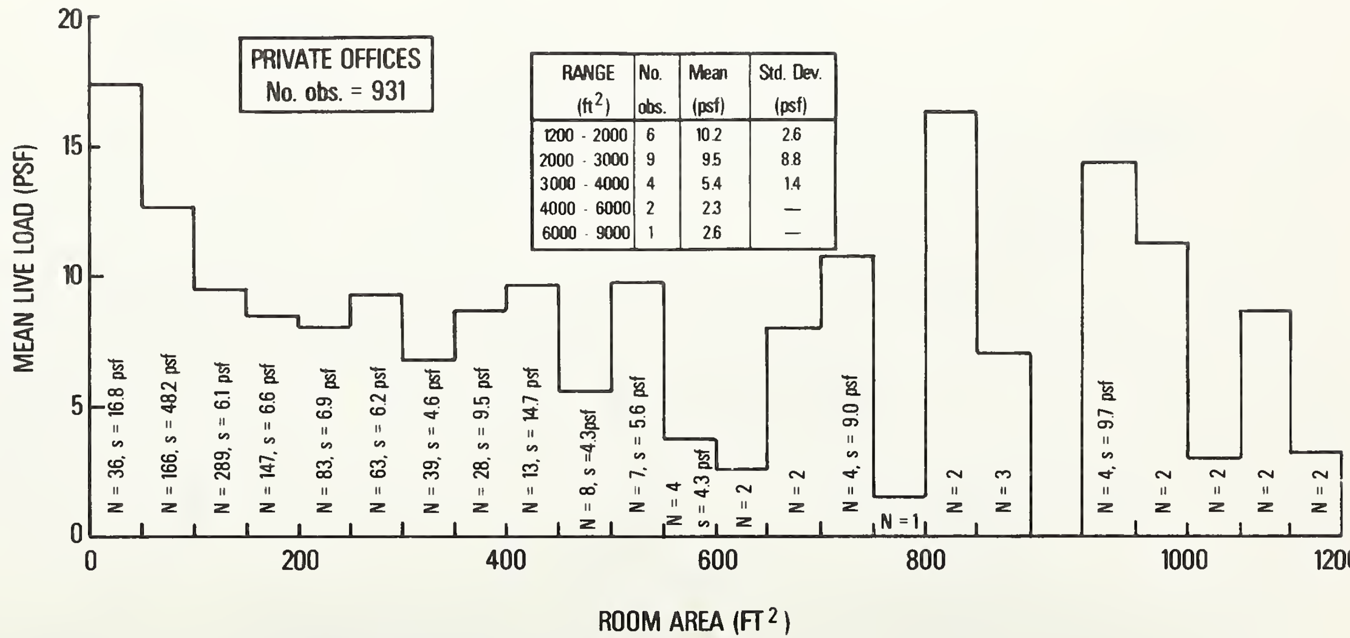


Figure 30 - Live Load versus Room Area - Private Offices

3.7 General Results

The survey data provided detailed information on the characteristics of rooms in office buildings in addition to the loads discussed in previous sections. This included information on the bounding surfaces, openings, and room contents which is summarized in this section. Numerous additional studies can be made using the data collected.

The characteristics of the bounding surfaces (walls, floor, ceiling) are of interest with respect to fire growth and fire severity studies. Data on these characteristics are presented in Table 31. For each item, the types of material correspond to the choices available on the data collection form. The number of occurrences for each of the 1354 rooms and the frequency of occurrence are given. The sample size for the walls was obviously four times that of the room sample. Referring to Table 31, it may be noted that: (1) the ceiling material was acoustical tile in most cases, (2) the majority of floors were covered with carpet or resilient tile and very few wood floors were encountered, (3) most doors were metal although many doors had a plastic veneer type finish, (4) most baseboard molding was rubber or metal, (5) noncombustible and metal wall panels were predominant (some rooms with one or more open walls occurred - wall material not present), and (6) the majority of the walls were painted.

Since the severity of a fire in a room is affected by the dimensions of the openings through which air for combustion can be supplied, data on the doors and windows in the offices were obtained. These data are presented in Table 32 according to room use and occupancy type. The percentage of wall area composed of doors and windows and the opening factor or temperature factor are given. The fire duration in hours is directly related to the fire load and this opening factor (13). The percentage of door and window area appears to be related to room use with file rooms and storage rooms having the smaller values as expected. In most cases, rooms in private buildings have a larger percentage of door and window area. The opening factors for government general and clerical offices in Table 32 are approximately equal to the "medium" values for this parameter used in analytical studies by Lie and Stanzak (14). The values for government lobbies, conference rooms, and file rooms are close to their "small" values. The opening factor for private general offices agrees with their "large" opening factor. Note that the opening factor for each room use in Table 32 varies considerably and in most cases the coefficient of variation is greater than one.

Data on the number of concentrated loads in offices are given in Figure 31. The number of loads in this case refers to discrete individual floor loads. For example, a cabinet, including its contents and items on top of the cabinet, was considered as one load. The total includes all items from heavy pieces of furniture such as desks to small light items such as wastebaskets. The mean number of items was eighteen and the maximum 304. The large number of loads occurred in office landscape type areas, i.e. open office space comprising almost an entire floor. The few offices with a very large number of loads also account for the large coefficient of variation $\left(\frac{28.5}{17.6} = 1.6\right)$. About six percent of the rooms, primarily lobbies, contained five items or less.

TABLE 31 CHARACTERISTICS OF COMPARTMENT BOUNDING SURFACES

Item	Number of Observations and Percent of Total														Not Present
	Wood	Metal	Plastic	Acoustical Tile	Non Comb.	Res. Flooring	Carpet	Rubber	Plaster	Gypsum Board	Paper	Drapes	Vinyl	Paint	
Ceiling	1 0.1	5 0.4	6 0.4	1227 90.6	115 8.5	—	—	—	—	—	—	—	—	—	—
Floor	14 1.0	—	—	—	159 11.8	325 24.0	856 63.2	—	—	—	—	—	—	—	—
Doors	147 10.9	737 54.4	469 34.6	—		—	—	—	—	—	—	—	—	—	1 0.1
Floor Trim	138 10.2	296 21.9	120 8.9	—	—	—	—	734 54.1	—	—	—	—	—	—	66 4.9
Wall Material*	51 1.0	1658 30.6	24 0.4	—	1038 19.2	—	—	—	336 6.2	1951 36.0	—	—	—	—	358 6.6
Wall Covering*	—	—	—	—	—	—	—	—	—	—	0	375 6.9	275 5.1	4023 74.3	743 13.7

Government and private - sample size = 1354 rooms
(Only those rooms that were randomly selected were used for this table.)

*By wall

TABLE 32 SUMMARY OF DATA FOR DOORS AND WINDOWS

Occupancy Type	Room Use	No. of Rooms	Door Area plus Window Area / Total Wall Area x 100	No. of Rooms*	Opening Factor $A\sqrt{H}/A_T$
Government	General	342	12.7, 7.6	294	0.117, 0.103
	Clerical	77	11.2, 7.4	50	0.089, 0.084
	Lobby	15	14.8, 10.9	11	0.034, 0.057
	Conference	39	8.2, 5.6	37	0.033, 0.067
	File	10	6.0, 5.3	8	0.049, 0.070
	Storage	35	5.5, 3.4	34	0.008, 0.032
	Library	2	7.3, 7.6	2	0.064, 0.090
Private	General	479	17.8, 9.2	453	0.185, 0.136
	Clerical	146	13.3, 8.0	112	0.090, 0.110
	Lobby	45	14.5, 9.0	32	0.023, 0.046
	Conference	57	14.1, 9.9	56	0.087, 0.138
	File	20	11.1, 7.3	17	0.050, 0.111
	Storage	77	9.0, 7.0	70	0.007, 0.032
	Library	10	6.8, 4.7	7	0.035, 0.066

Values listed are sample mean and standard deviation - $\overline{X}$, s

A = Total window area

H = Height of window in feet

A_T = Total area for internal surfaces of room (walls, floor, ceiling)

*The opening factor was not computed for rooms without four full height walls.

(Only those rooms that were randomly selected were used for this table.)

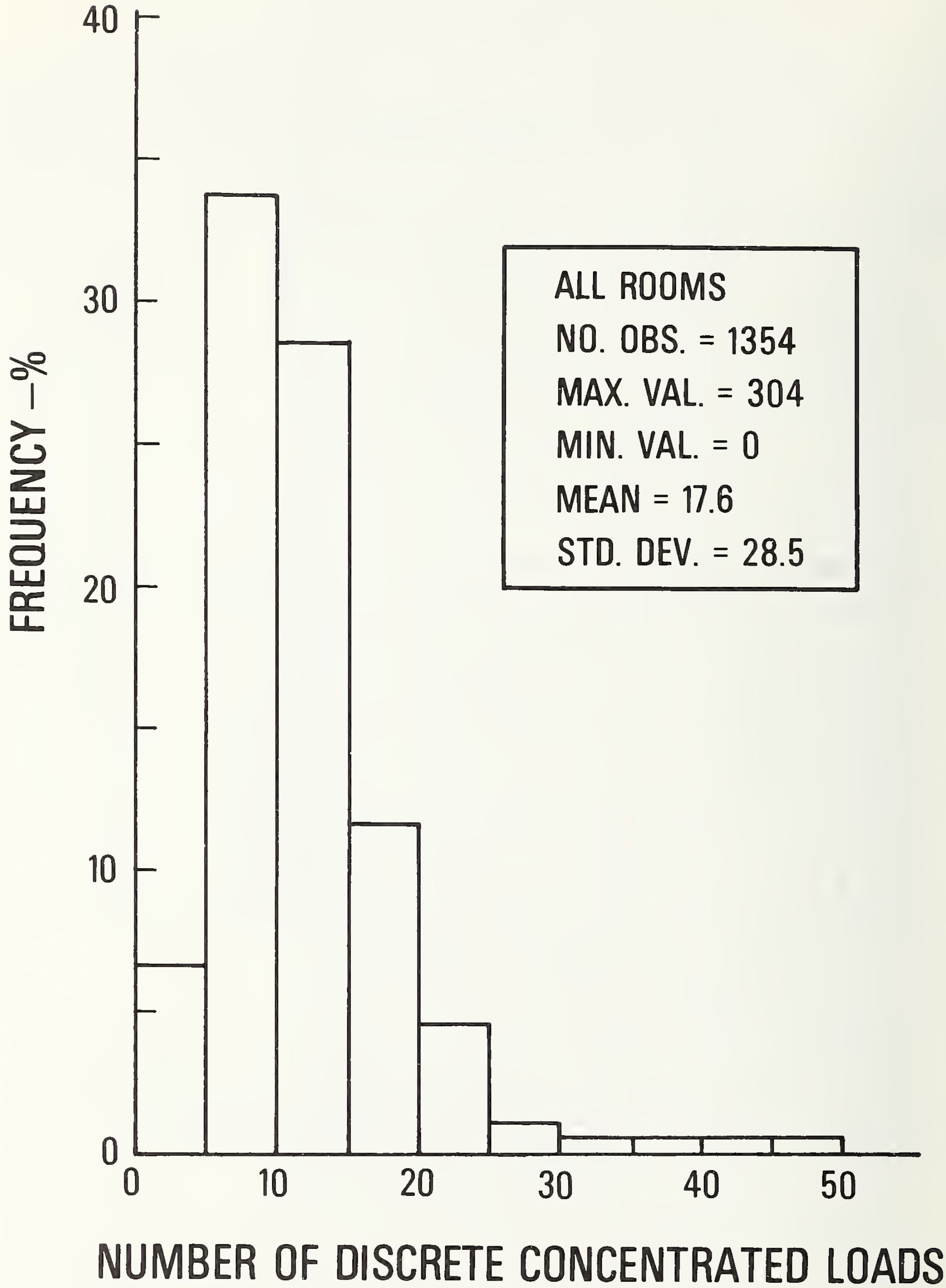


Figure 31 - Number of Discrete Loads in a Room

The characteristics of the types of furniture items observed in the offices surveyed are given in Table 33. The total number of desks, tables, etc. in the 1354 offices and the construction material are indicated. The material type in this case refers to the primary construction material and does not include laminate material used as a finish surface. The number of metal desks encountered was about twice the number of wood desks. The reverse was true for tables, however. As expected, the majority of filing cabinets were metal. General purpose cabinets were equally divided between the two material types. In the total survey only four pieces of plastic furniture were encountered.

The weight of heavy individual furniture items in offices is of interest in live load design. Existing standards, for example, require that floors be designed for concentrated loads in addition to the specified uniformly distributed loads. The frequency distribution for the heaviest load in each of the rooms surveyed is given in Figure 32. The maximum load encountered was 3280 lb. The mean for all the offices was 451 lb. The coefficient of variation of 0.63 for these data is of the same order of magnitude as that for the uniformly distributed live load (Figures 12 and 13 - 0.61) The 99 percent fractile load for the data in Figure 32 is 1748 lb which corresponds closely to the value of 2000 lb specified in existing standards for office buildings.

The amount of paper and books in offices is of interest with respect to fire considerations. The degree of compaction of this material is also important since it affects the rate at which it will burn. Table 34 lists the observed percent compaction of paper and books for various furniture items in the survey. Paper and books on top of furniture which are immediately available for combustion (free contents) and enclosed paper and books within drawers, shelves, etc. are listed separately. Since enclosed contents refer only to material completely enclosed on all sides, there are no data for enclosed paper and books for shelving, seating, and miscellaneous items. The number of observations in each case refers to the number of distinct piles or stacks encountered for all the desks, tables, etc. The data indicate that piles of paper occurred more frequently than piles of books. The number of piles of free and enclosed paper were about the same for desks. For cabinets, the number of enclosed paper piles was twice the free content piles. The percent compaction generally ranged from 85 to 95 percent.

The spatial distribution of the loads in a room is important from the standpoint of the live load effect on the structural systems and the transmission of heat to the bounding surfaces in the case of a fire. Data on this distribution are presented in Figures 33 and 34 and Table 35. The data in Figures 33 and 34 indicate a definite tendency for the items in a room, particularly the heavier items which contribute the major portion of the total room load, to be located near the walls (within 2 ft). Both distributions indicate a negative skew although there appears to be an slight tendency toward a bimodal distribution. Apparently in arranging the contents of offices, the occupant either

TABLE 33 CHARACTERISTICS OF ROOM FURNITURE

Type of Item	Total No. of Items	Number of Observations and Percent of Total		
		Wood	Metal	Plastic*
Desk	2162	755 34.9	1407 65.1	0
Table	1502	912 60.7	589 39.2	1 0.1
Filing Cabinet	1608	74 4.6	1534 95.4	0
File Safe	32	2 6.3	30 93.8	0
Blueprint Cabinet	23	0	23 100.0	0
Card File	120	7 5.8	113 94.2	0
General Purpose Cabinet	1048	503 48.0	544 52.0	1 0.1
Bookcases	1014	356 35.1	658 64.9	0
Free Shelving	521	247 47.4	272 52.2	2 0.4
Chairs (Frame material)	4588	2840 61.9	1748 38.1	0

Government and private - sample size = 1354 rooms

*Does not include wood or metal items with plastic laminate finish surfaces

(Only those rooms that were randomly selected were used for this table.)

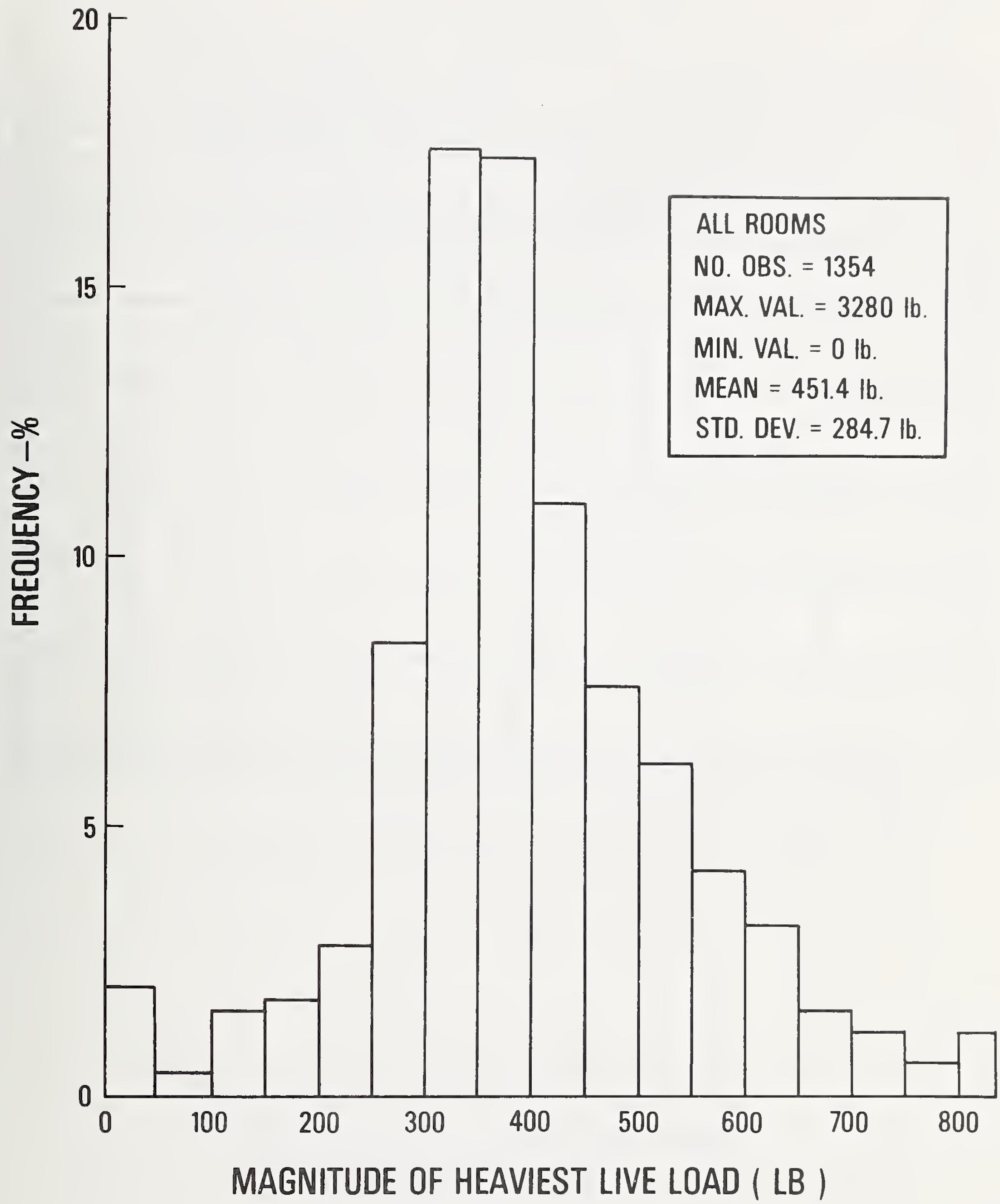


Figure 32 - Magnitude of Heaviest Room Load

TABLE 34 COMPACTION OF PAPER
AND BOOKS

Type of Item	Percent Compaction for Paper and Books							
	Free				Enclosed			
	Total No. of Obs.	Free Book	Total No. of Obs.	Free Paper	Total No. of Obs.	Enclosed Books	Total No. of Obs.	Enclosed Paper
Desk	636	90.5	1999	96.8	789	87.8	1949	84.9
Table	432	88.3	850	94.8	33	93.9	165	95.9
Cabinet	635	87.0	1031	93.9	699	81.8	2318	82.7
Shelving	958	83.5	897	88.0	—	—	—	—
Seating	1	100.0	3	93.2	—	—	—	—
Miscellaneous	46	92.0	252	83.9	—	—	—	—

Government and private - sample size = 1354 rooms

Values listed are sample mean and standard deviation - $\overline{X}$, s

(Only those rooms that were randomly selected were used for this table.)

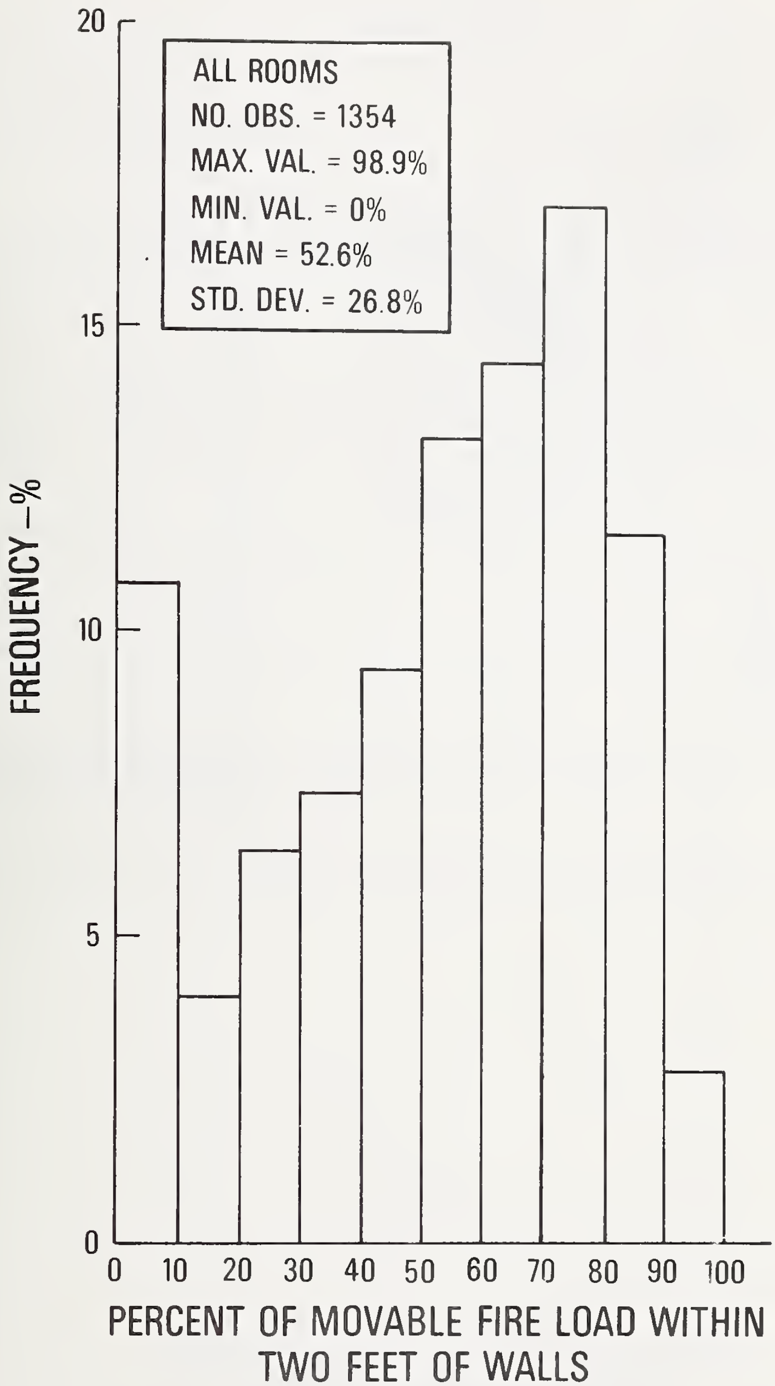


Figure 33 - Distribution of Fire Load in Rooms

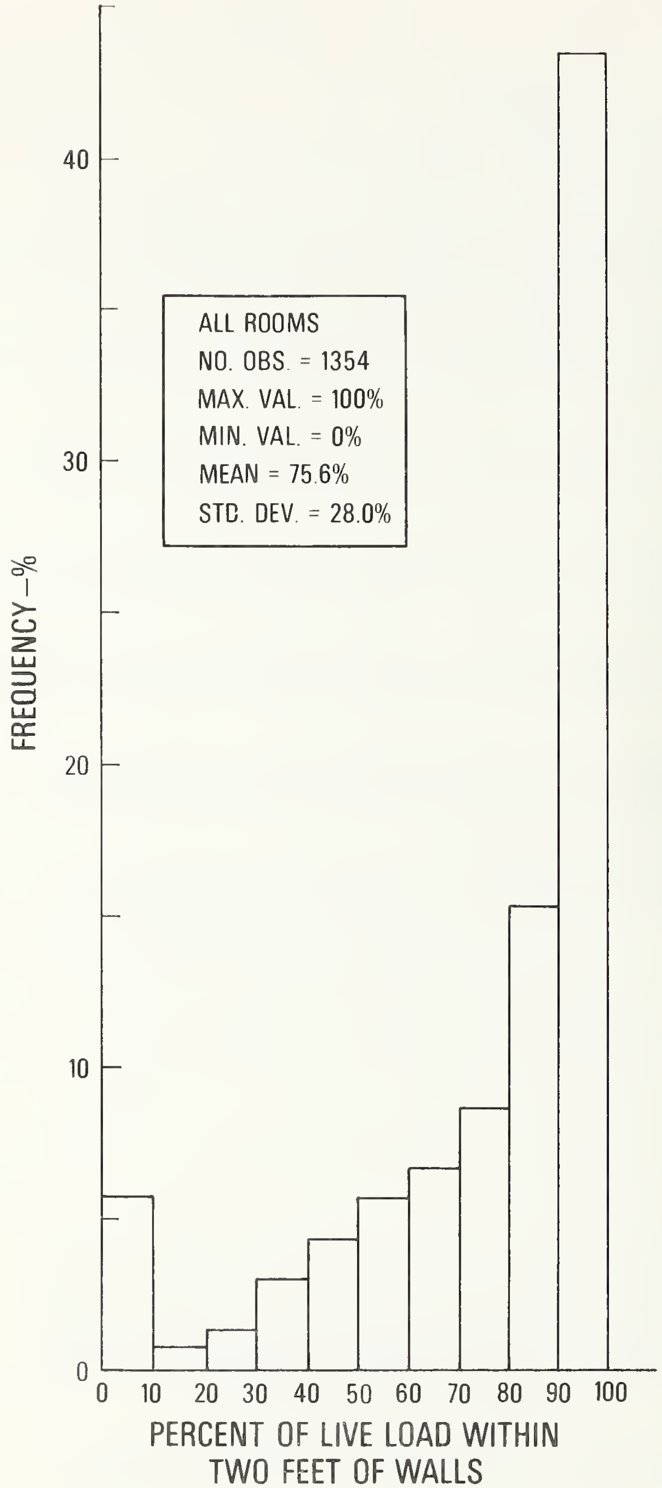


Figure 34 - Distribution of Live Load in Rooms

TABLE 35 SPATIAL DISTRIBUTION
OF ROOM CONTENTS

Type of Item	Government Offices		Private Offices	
	No. of Items	Percent within 2 feet of walls	No. of Items	Percent within 2 feet of walls
Desk	965	55.1	1197	55.5
Table	847	69.8	655	61.8
Cabinet	1217	95.7	1614	84.6
Shelving	716	72.5	819	81.7
Seating	3891	35.0	4162	31.8
Miscellaneous	2979	65.2	4310	54.7

Government and private - sample size = 1354 rooms
Values listed are sample mean

(Only those offices that were randomly selected were used for this table.)

locates most of the items close to the walls or a very small portion near the walls, the former case occurring more frequently. The mean values of the live load and fire load within two feet of the walls were 75.6 percent and 52.6 percent respectively. The lower mean for the fire load percentage may be due to the fact that the derated movable fire load was used in Figure 34.

The spatial distribution of the various types of furniture items is given in Table 35. As expected, cabinets and shelving are more frequently close to the walls. About half of the desks and somewhat more than half of the tables were within two feet of the walls. Most of the seating was greater than two feet from the walls. Although some differences occurred between private and government offices, there is no apparent trend.

The percentage of the room floor area occupied by furniture provides an indication of the degree to which office space is utilized and is an important consideration relative to the amount of space available for additional furniture loads or loads which could occur due to people crowding into a particular room under certain circumstances (emergencies, parties, etc.). Obviously, the smaller the percentage occupied, the greater the additional load could be. Data on this parameter are given in Figure 35 for general and clerical offices. About 60 percent of the data fall in the 20 to 40 percent range with a mean value of 33.5 percent. The variation (coefficient of variation = 0.42) is somewhat less than that discussed previously for load magnitude and the distribution is approximately normal. The variation of this ratio as a function of the area of the room is presented in Figure 36 for all the room use types. The mean value seems to decrease slightly with room area. For rooms less than 100 ft^2, approximately 40 percent of the floor area is occupied. This value decreases to between 25 to 30 percent for larger areas. Table 36 summarizes data on this parameter as a function of room use. The fractile values were obtained directly from the ordered data. The minimum values of zero correspond to empty offices and lobby areas with no live load. The mean value of the occupied floor area was approximately the same for the different room uses except for lobbies. The scatter of coefficient of variation was much larger for storage rooms than the other uses. More variation occurred for the 95 percent fractile, however, with the largest values being for clerical offices and storage rooms.

The survey data presented thus far indicate that a variety of factors may affect the load characteristics and loads in offices to varying degrees. Although the concept of discussing these quantities in terms of a "typical" office is questionable, it is of interest to summarize the mean values. Data on factors related to fire consideration are given in this form in Table 37 for the 1044 randomly selected general and clerical offices in the survey. Mean values for both the total and derated fire loads, the movable contents and interior finish fire loads, the characteristics of these loads and information on the openings are included. Derated fire loads were obtained using the derating factors presented in a previous report to account for the estimated quantity of enclosed combustibles which will burn in a fire (5).

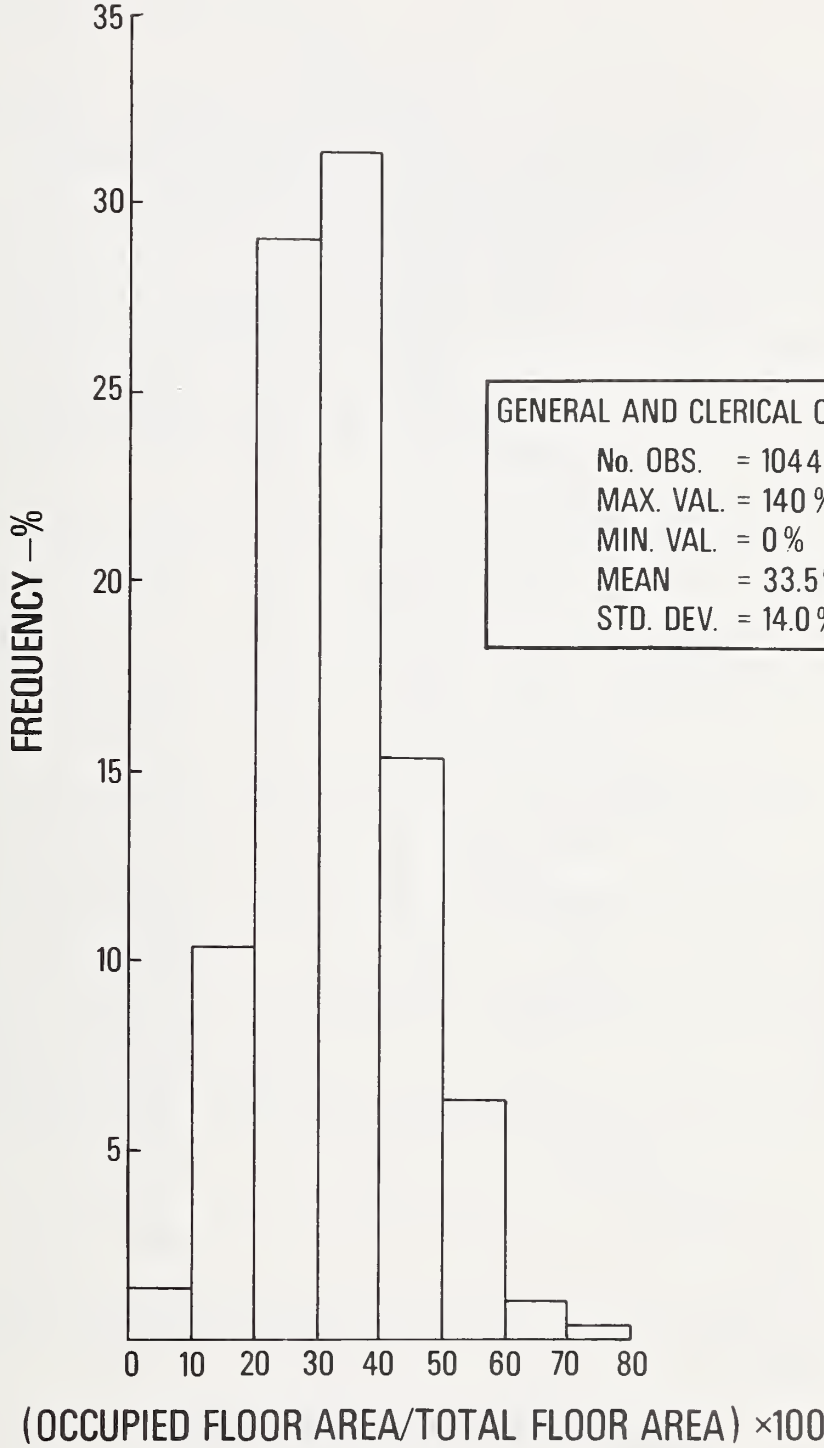


Figure 35 - Frequency Distribution of Loaded Floor Areas

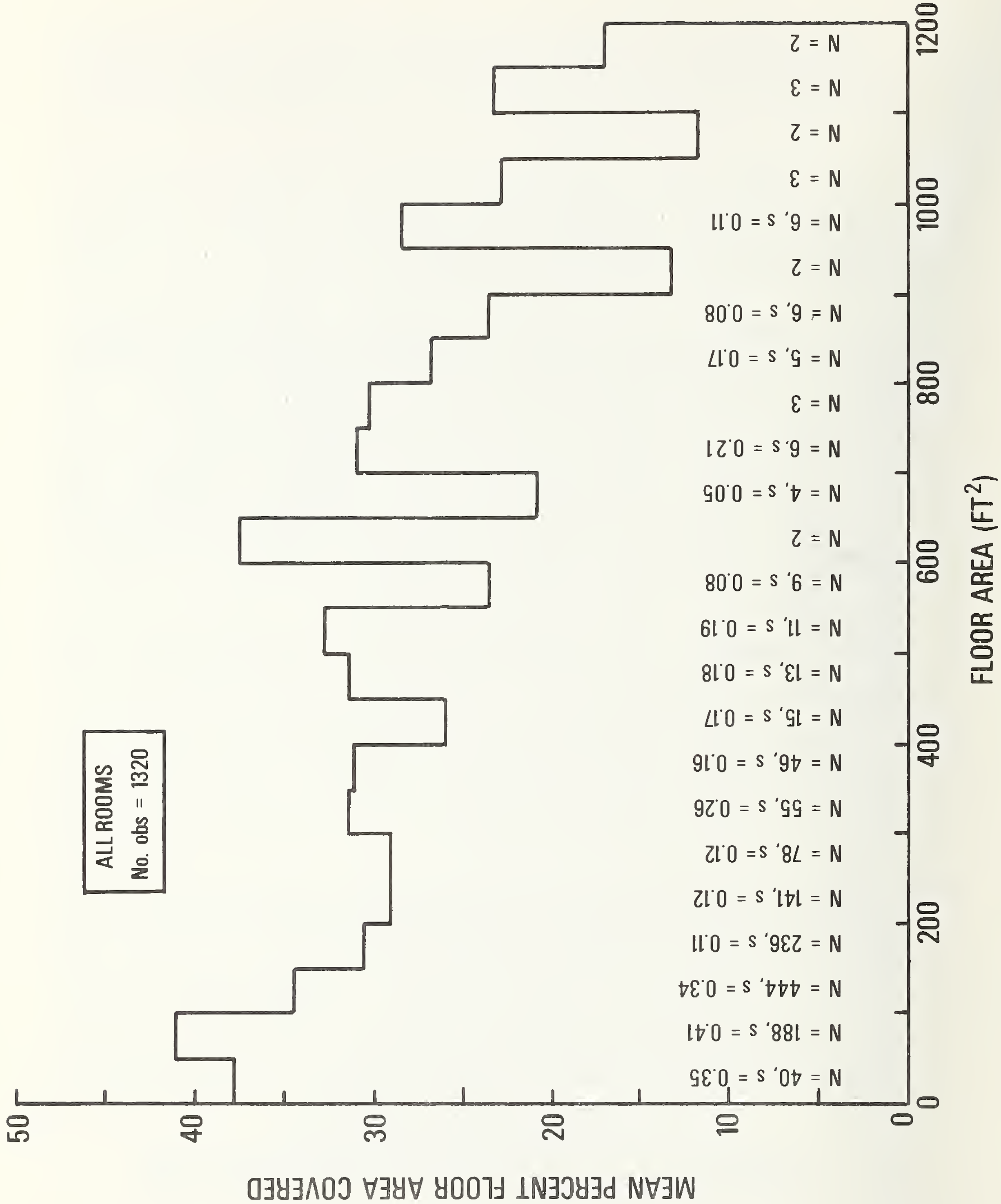


Figure 36 - Variation of Occupied Area with Floor Area

TABLE 36 SUMMARY OF OCCUPIED FLOOR AREA

Room Use	No. of Rooms	Occupied Floor Area/Total Floor Area					
		Minimum Value	Lower 5% Fractile	Maximum Value	Upper 95% Fractile	Mean Value	Standard Deviation
General	818	0.0	15.6	90.2	53.9	33.1	12.4
Clerical	222	0.0	13.7	97.9	73.8	34.1	17.0
Lobby	60	0.0	0.0	65.2	43.4	20.2	13.8
Conference	95	9.7	15.4	84.6	59.5	36.1	14.1
File	30	1.2	5.9	87.1	62.9	35.4	19.1
Storage	111	0.0	0.0	92.1	75.0	27.5	21.0
Library	12	22.1	—	58.3	—	36.6	10.9

Government and Private Buildings

(Only those rooms that were randomly selected were used for this table.)

TABLE 37 PROFILE OF OFFICE FIRE LOADS

General and Clerical Offices - Sample Size = 1044 offices
(Government and Private)

1.	Total fire load	=	7.3 psf, 4.4 psf
2.	Total fire load (derated)	=	6.6 psf, 4.1 psf
3.	Movable contents fire load (derated)	=	5.0 psf, 4.0 psf
4.	Interior finish fire load	=	1.6 psf, 0.5 psf
5.	Percent of total derated fire load enclosed in metal containers	=	9.1%, 12.4%
6.	Percent of furniture and miscellaneous items within 2 feet of the walls*	=	70.2%, 20.4%
7.	Percent of total fire load within 2 feet of the walls	=	55.1%, 23.6%
8.	Percent of total fire load that is paper and books	=	38.6%, 22.9%
9.	Number of free standing items	=	16.9, 27.6
10.	Opening Factor ($A\sqrt{H}/A_T$)**	=	0.146 $ft^{1/2}$, 0.127 $ft^{1/2}$
11.	Percent of floor area occupied	=	34%, 19.1%

* Sample Size = 1034

**Sample Size = 909

Values listed are sample mean and standard deviation - $\overline{X}$, s

(Only those rooms that were randomly selected are used for this table.)

e following observations can be made from the data in Table 37:

(1) The derated fire load is approximately 90 percent of the total fire load,

(2) Movable contents comprise approximately three-fourths of the derated fire load,

(3) The majority of the furniture items are within two feet of the walls,

(4) Paper and books account for approximately 40 percent of the total fire load, and

(5) On the average, 34 percent of the floor area is covered by furniture, equipment, etc.

3.8 Load Models

As indicated in the Introduction, the purpose of this survey was to identify the factors affecting the magnitude of loads in office buildings and to then develop a mathematical model for predicting future loads. The model could be used for future building populations with a different relative mix of building and occupant characteristics (building height, firm age, etc.) than the current population surveyed. It was assumed that time would not significantly change the effect of the various parameters, e.g. if the load magnitude in present-day buildings is related to room use and file rooms are x percent heavier than clerical offices, file rooms in future buildings would continue to be x percent heavier than clerical offices. This assumption regarding time effects obviously needs to be verified.

The influence of building and occupant characteristics on load magnitude can be considered at two levels, loads in rooms and loads on larger areas such as structural bays. The latter is obviously more significant from the standpoint of design requirements. Factors such as room use and area can be referred to as "local" factors and may affect the loads in individual rooms. One would expect, however, that these mean room loads would not be affected by factors such as building height and building age. The loads on larger areas or structural bays, however, may be affected by these building factors since the arrangement of rooms may be related to building height, type of occupancy, etc. The survey data may be used for both cases. The analysis in this report considers only loads in rooms. The influence of building factors (i.e. arrangement of rooms in the buildings) on loads on structural bays can be determined using the floor plan data (6). Additional analysis is required to determine this influence.

Since the twenty-three buildings did not conform to a factorial experiment design, a linear regression analysis was used to derive the mathematical models. A step wise regression analysis of the data was carried out using the BIOMED computer program (6). The following form was used for the mathematical model:

$$E[Y]_x = C_o + \sum_{i=1}^{n} C_i x_i$$

The term, $C_i x_i$ represents the main effect of the variable x_i. Several combinations of variables were used in order to identify the significant factors. Regression analyses were carried out using the following combinations: (1) room use; (2) room use and room area; (3) room use and firm type; (4) room use, firm type, and geographic location; (5) room use, firm type, geographic location, occupancy duration, building age, building height, and room area. In all cases, room use was found to be the most significant factor, i.e. it contributed almost all the variance in the live load and fire load accounted for in the regression analysis. Room use, therefore, was the only variable included in the mathematical models [Equations 1 and 2] .

The mean and standard deviation for the data from all the 1354 rooms were as follows: Live Load - $\bar{x}$ = 9.9 psf, S = 8.6 psf; Total Fire Load - $\bar{x}$ = 7.8 psf, S = 6.8 psf. The final equations developed from the regression analysis give the following predicted mean values:

$$\text{Mean Live Load (psf)} = 13.8 - 4.6x_1 - 3.7x_2 - 9.8x_3 - 8.1x_4 + 11.5x_5 + 2.0x_6 + 12.7x_7 \tag{1}$$

$$\text{Mean Total Fire Load (psf)} = 11.1 - 3.6x_1 - 4.7x_2 - 6.7x_3 - 5.9x_4 + 5.7x_5 + 1.6x_6 + 13.6x_7 \tag{2}$$

The independent variables x_i in Equations 1 and 2 correspond to the following room use types:

x_1 - general office
x_2 - clerical office
x_3 - lobby
x_4 - conference room
x_5 - file room
x_6 - storage room
x_7 - library

Each variable takes on the value of one or zero and only one of the seven is nonzero at a time depending on the type of room for which the equations are used. For example, the mean live load for storage rooms is obtained from Equation 1 by setting $x_1 = x_2 = x_3 = x_4 = x_5 = x_7 = 0$ and $x_6 = 1$, i.e. $E\,[\text{Live Load}]_{\text{storage}} = 13.8 + 2.0 = 15.8$ psf. The standard deviations associated with Equations 1 and 2 obtained from the average of the squared residuals in the regression analysis are 7.8 psf and 6.2 psf, respectively. The magnitude of the coefficients in Equation 1 suggest that some of the room types could be combined as follows: general and clerical; lobby and conference; and file and library which would reduce Equation 1 to four independent variables, three of which take on nonzero values for two room uses, i.e. $x_1 = 1$ for either general or clerical offices. For the purposes of this report, the seven independent room use types were retained.

Although previous surveys (8) and the data in Figures 23-26 suggest that the fire load and live load are related to the area of a room, the regression analysis using room use and room area did not indicate that area had a significant effect. The results obtained including both room use and area were as follows:

$$\text{Mean Live Load (psf)} = 9.5x_1 + 10.7x_2 + 4.4x_3 + 6.1x_4 + 26.0x_5 + 16.1x_6 + 26.8x_7 - 0.00134 \text{ Area } (ft^2) \quad (3a)$$

$$\text{Mean Total Fire Load (psf)} = 7.7x_1 + 6.9x_2 + 4.7x_3 + 5.5x_4 + 17.3x_5 + 12.9x_6 + 25.0x_7 - 0.00098 \text{ Area } (ft^2) \quad (3b)$$

Note that the form used for Equations 3 is somewhat different from that used for Equation 1, i.e. no constant term. For general offices of different size, the live load from Equations 3 would be: Area = 50 ft^2, Live Load = 9.4 psf; Area = 100 ft^2, Live Load = 9.4 psf; Area = 150 ft^2, Live Load = 9.3 psf; Area = 300 ft^2, Live Load = 9.1 psf; Area = 500 ft^2, Live Load = 8.9 psf. This decrease in load with increase in area is considerably less than that indicated in Figures 23 through 26. Similar results occur for the other room uses.

The preceding analysis suggests that room use and room area may be correlated, i.e. file rooms may normally be small rooms, conference rooms and lobbies large rooms, etc. A regression analysis was performed in which the coefficient for the area term in Equations 3 was related to the room use. The results obtained for this case were as follows:

$$\text{Mean Live Load (psf)} = (9.5 - 0.00135A_1)x_1 + (10.7 - 0.00123A_2)x_2 + (4.7 - 0.00216A_3)x_3 + (6.4 - 0.00214A_4)x_4 + (26.3 - 0.00179A_5)x_5 + (16.0 - 0.00067A_6)x_6 + (22.4 - 0.01509A_7)x_7 \quad (4a)$$

$$\text{Mean Total Fire Load (psf)} = (7.8 - 0.00129)x_1 + (6.8 - 0.000085)x_2 + (5.2 - 0.00271)x_3 + (6.1 - 0.0028)x_4 + (17.0 - 0.00038)x_5 + (13.0 - 0.00179)x_6 + (20.1 + 0.01680)x_7 \quad (4b)$$

The results in Equations 4 indicate that the decrease in load with increasing area is different for the various room uses. The decrease is largest for lobbies and the load in libraries actually increases with increase in area.

Results from the regression analysis suggest that the variation of load with area is related to room use. The trend observed in Figures 23 through 26 and in previous surveys may be due to the fact that the smaller heavier rooms are primarily one type of room (e.g. file, storage) and the larger lighter rooms are another type. The influence of area on load magnitude requires further study. Prior to developing live load reduction factors for design purposes, it may be important to determine the degree to which the position of various room types is correlated. One would expect, for example, that the reduction factor for areas comprised primarily of file rooms would be different from that for areas comprised of general offices.

3.9 Evaluation of Load Models

In order to evaluate the load models, the majority of rooms were surveyed in Buildings 14, 24, and 27. These three buildings were selected prior to deriving the load models in Section 3.8. Their characteristics (height, age, geographic location, occupancy) were similar to the other 20 buildings used to develop the load models. As indicated in Section 3.3, only 25 percent of the rooms for each of these three buildings was combined with the data for the other buildings to develop the load models in Section 3.8. The evaluation procedure involved using the first load model (Equations 1 and 2 in Section 3.8) to calculate the loads in all the rooms in these three buildings and then comparing these loads with the survey values. This was carried out using the BUILDER computer program discussed in Reference 6.

The results of the evaluation are given in Table 38 and Figures 37 through 41. Differences between the measured (surveyed) and calculated loads for each room in the three buildings are summarized in Table 38 separately for each building and for all the rooms. For Buildings 14 and 27 the mean value of the difference was negative, i.e. the measured loads were less than the calculated values. For Building 24, the reverse was true. For the 863 rooms in the three buildings the mean difference was less than 1 psf for live load. One would expect this difference to approach zero as the number of buildings considered increased.

The standard deviation for the difference between measured and calculated loads for room loads was approximately the same as that for the load models in Section 3.8. This is also as expected since the variation in loads between rooms in the three buildings was probably similar to that for the buildings used to derive the load models.

Histograms illustrating the differences between measured and calculated loads for the three buildings are given in Figures 37 through 40.

Differences between the measured and calculated values for the total load on each floor are also summarized in Table 38. Only loads for the offices surveyed were considered in obtaining these floor loads. Loads in unsurveyed rooms, corridors, stairways, etc. were not considered. The differences are expressed in absolute terms (kips) and also as a percent difference. The histogram for the percentage difference for all the floors in the three buildings is given in Figure 41. As in the case of room loads, the measured floor loads for Buildings 14 and 27 were less than calculated (mean percent difference negative) and those for Building 24 were greater. For all 39 floors in the three buildings, the mean percent difference is 40 percent. The coefficient of variation for the floor live loads (59/40 = 1.48) is greater than that for the load model (Equation 1, Section 3.8).

Differences between the measured and calculated values for the total load in each building are also given in Table 38. As with room and floor loads, the measured loads were less than calculated for Buildings 14 and 27. The mean percent difference for all three buildings was 8 percent.

TABLE 38 COMPARISON BETWEEN CALCULATED AND MEASURED LOADS

Load	Building No.	No. Obs.	Measured Load - Calculated Load							
			Total Fire Load				Live Load			
			Min.	Max.	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.
Room Load (psf)	14	291	- 13.2	37.6	- 1.4	6.0	- 19.8	52.3	- 1.6	8.3
	24	151	- 11.6	35.7	3.4	6.1	- 10.1	35.7	5.5	7.4
	27	421	- 18.1	27.3	- 3.4	4.0	- 22.3	38.2	- 2.8	5.7
	14, 24, & 27	863	- 18.1	37.6	- 1.5	5.7	- 22.3	52.3	- 0.9	7.6
Floor Load (kips)	14	16	- 25.9 (-145)	8.2 (13)	- 7.9 (-41)	10.7 (45)	- 39.3 (-142)	37.5 (35)	- 9.4 (-43)	17.4 (46)
	24	7	10.4 (15)	30.0 (38)	16.7 (26)	8.0 (9)	- 6.1 (-12)	57.9 (49)	29.1 (29)	20.3 (20)
	27	16	- 8.4 (-359)	59.2 (38)	- 21.6 (-120)	28.4 (113)	- 8.2 (-196)	86.3 (38)	- 17.7 (-66)	32.2 (60)
	14, 24, & 27	39	- 25.9 (-145)	59.2 (38)	- 9.1 (-61)	23.8 (94)	- 39.3 (-142)	57.9 (49)	- 5.9 (-40)	29.7 (59)
Building Load (kips)	14	1	--	--	-126.4 (-31)	--	--	--	-150.8 (-29)	--
	24	1	--	--	117.1 (27)	--	--	--	-203.4 (33)	--
	27	1	--	--	-345.2 (-56)	--	--	--	-284.0 (-29)	--
	14, 24, & 27	3	-345.2 (-56)	117.1 (27)	-118.2 (-20)	231.3 (43)	-284.0 (-29)	203.4 (33)	- 77.1 (-8)	251.9 (36)

Values in parentheses are based on values for the percent difference = $\left[\frac{\text{Measured Load - Calculated Load}}{\text{Measured Load}}\right] \times 100$

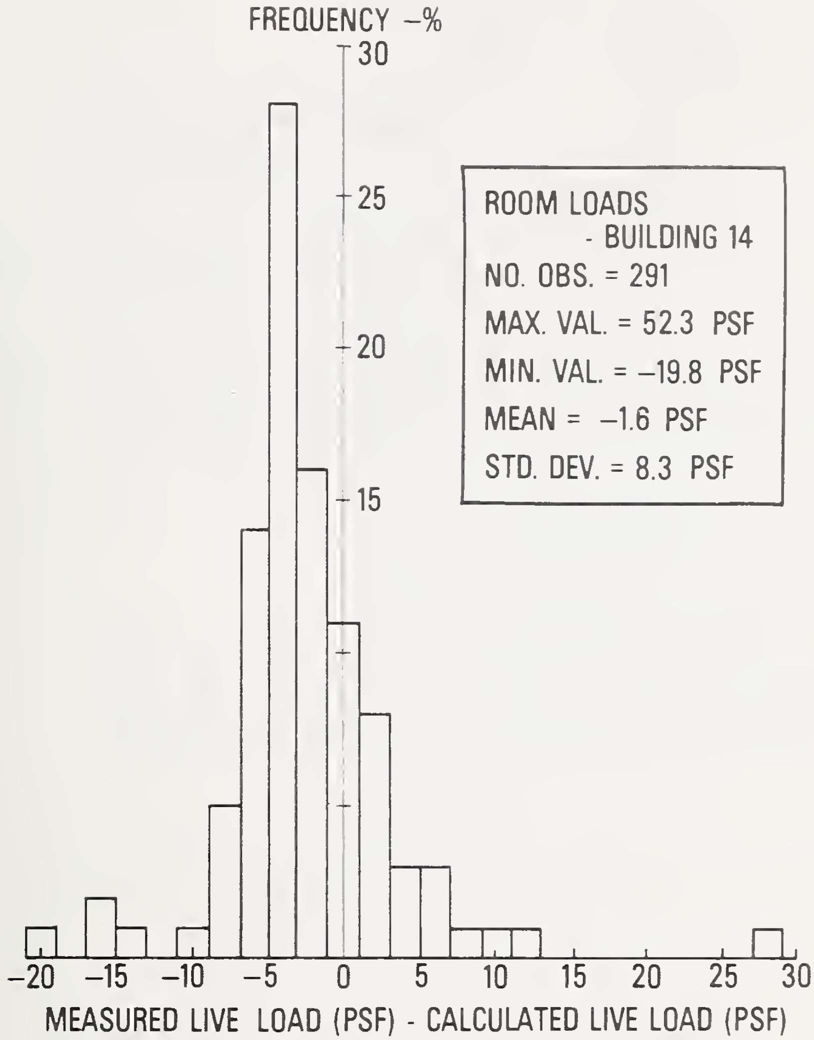


Figure 37 - Difference Between Measured and Calculated Room Live Loads--Building 14

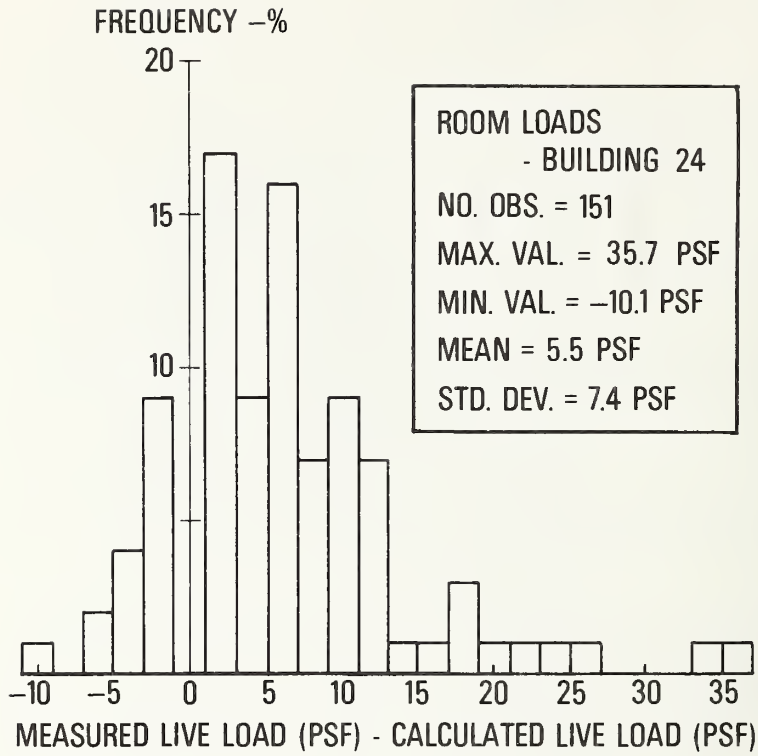


Figure 38 - Difference Between Measured and Calculated Room Live Loads--Building 24

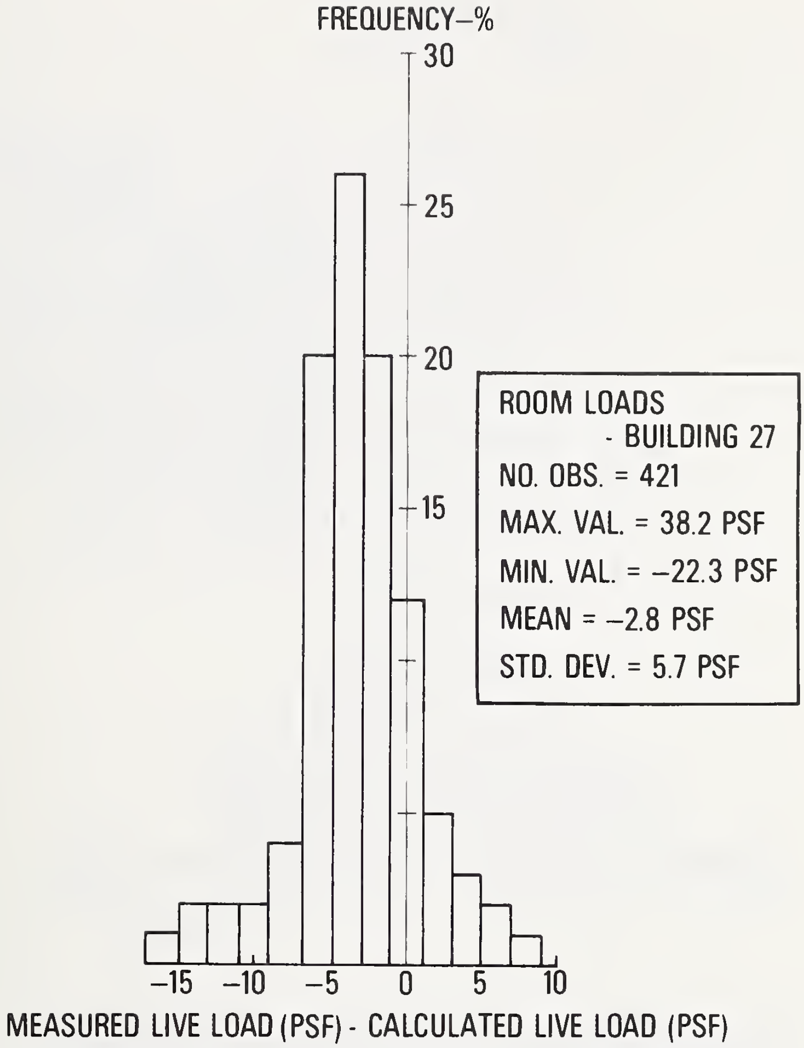


Figure 39 - Difference Between Measured and Calculated Room Live Loads--Building 27

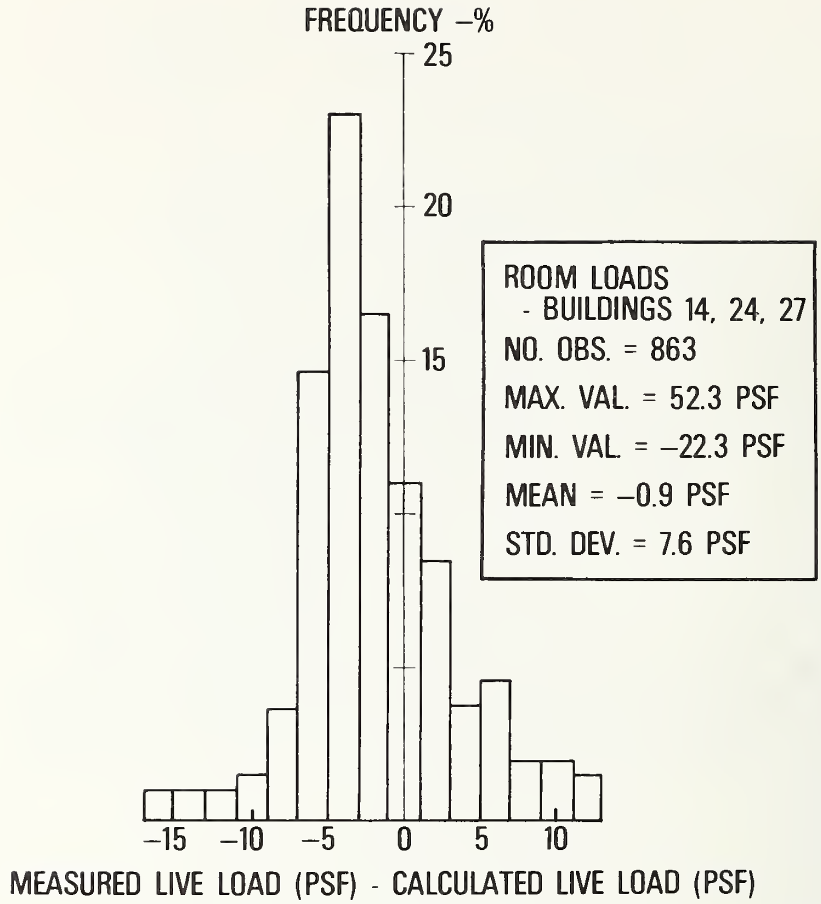


Figure 40 - Difference Between Measured and Calculated Room Live Loads--Buildings 14, 24, and 27

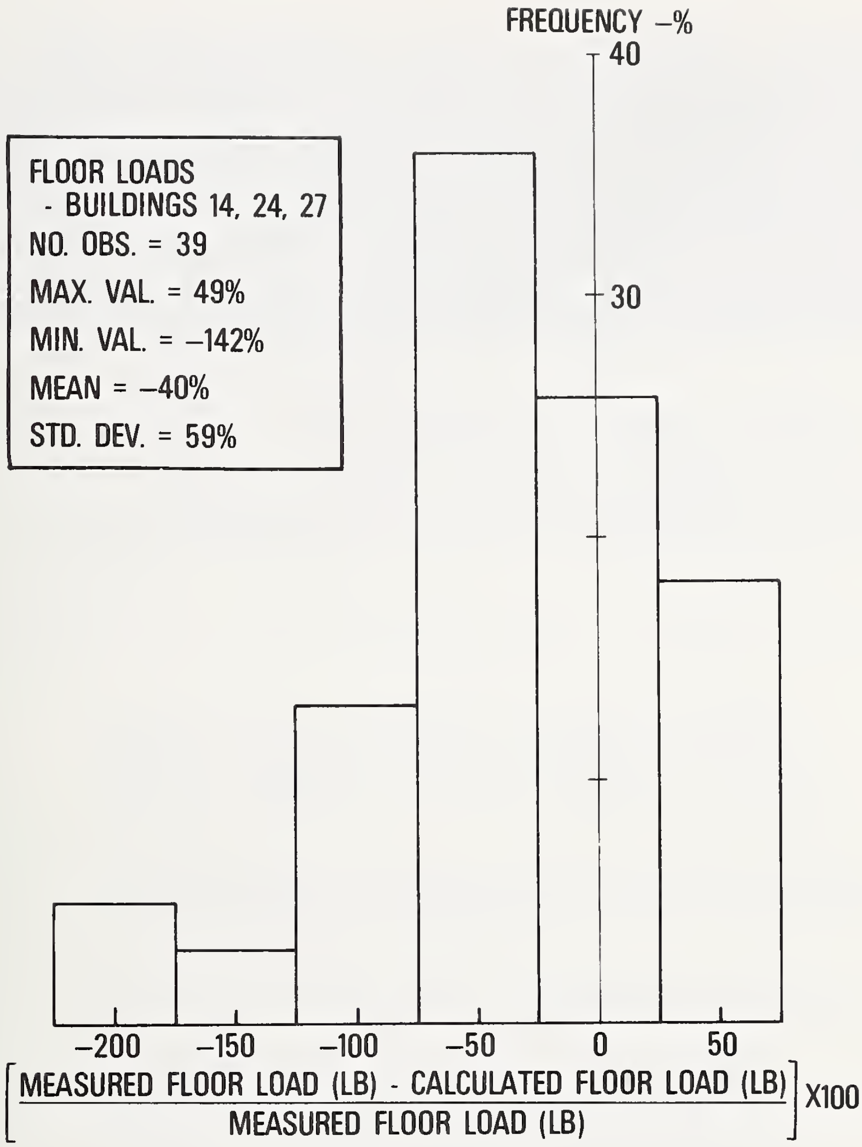


Figure 41 - Difference Between Measured and Calculated Floor Live Loads--Buildings 14, 24, and 27

The comparison indicated that the loads in two of the three buildings were less than the calculated loads and greater than the calculated values in one building. One would expect similar results if three other buildings from the survey sample were used for comparison with the models. As the number of buildings included in the comparison increases, the mean value for the difference between measured and calculated loads should approach zero. In view of the inherent variability in loads from room to room, however, one would expect the standard deviation for this difference to be approximately the same as that for the load models in Section 3.8. Similar results should occur for comparisons with other buildings not included in the survey if the loads in the 23 buildings used to derive the load models are representative of those in the population of office buildings.

4. SUMMARY AND CONCLUSIONS

This survey was designed to identify the factors such as building height, building age, geographic location, etc. which affect the magnitude of fire loads and live loads in office buildings. A special survey technique and data processing procedures were developed to economically and efficiently collect data from a large number of buildings. Twenty-three office buildings both Federal and private, from thoughout the United States were surveyed. Buildings ranging in height from two stories to forty-nine stories were included. The total number of rooms surveyed was 2433, of which 74 percent were general and clerical offices. The complete record of all the original field survey data was retained on microfilm and will be available for continuing studies and analysis.

Survey results were presented evaluating the influence of building characteristics (height, age, location), occupant characteristics (firm type), and room characteristics (room size, room use) on the magnitude of fire loads and live loads. The data were utilized to develop mathematical models for predicting load magnitudes in office buildings. Recommendations were also developed for additional research on loads in office buildings based on results obtained from the survey.

Based on the survey results presented herein, the following conclusions were obtained:

1. The measurement error associated with the inventory technique used in this survey was approximately 10 percent. This represents a relatively small fraction of the variability of live loads from room to room in office buildings.

2. The magnitude of the loads in rooms in office buildings is not affected by the geographic location of the building, building height, or building age.

3. There does not appear to be any significant difference between loads in government and private office buildings.

4. The magnitude of room fire loads and live loads is related to the use of the room. Libraries, file rooms, and storage rooms were the most heavily loaded. In general, the mean room load decreases as the area of the room increases although room use and room area may be correlated. Further study is required to establish the influence of area on load magnitude.

5. The variation of load with time requires further study. Although the mean load for the NBS Administration Building increased over a period of seven years, there was no clear indication of such a trend based on a comparison of mean load versus occupancy duration for the other buildings surveyed.

6. There is a definite tendency for loads in offices to be concentrated around the perimeter of the room.

7. Mean values of occupancy duration for government and private firms were 8.4 years and 7.9 years respectively. This difference is not statistically significant.

8. The interior finish fire load in a room ranged from 1.0 psf to 1.9 psf. The contribution of interior finish to the total fire load ranged from less than five percent to as high as fifty percent depending on room use.

9. The mean number of discrete concentrated floor loads in the rooms surveyed was eighteen.

10. The 99 percent fractile for the heaviest load in a room is quite close to the value currently used for designing office buildings.

11. In the majority of offices surveyed, between 20 and 40 percent of the floor area was occupied by furniture and equipment.

5. Research Recommendations

Prior to undertaking any additional survey work or implementing the research results obtained from this study, it is recommended that additional analysis be done using the available data. The data have been summarized herein in terms of means, standard deviations and range. Further analysis should be undertaken to estimate tolerance limits and fractile values using the means and standard deviations presented and assumptions regarding the form of the distributions. The necessity for improving the accuracy of the load models should be established and the implications of the survey results relative to existing design requirements for buildings should be examined. The survey data should also be used to assess design load magnitudes, live load reduction factors, fire endurance requirements, etc. currently in use. A detailed plan for this activity should be prepared. As a minimum this effort should include:

1. Determine horizontal and vertical correlation of loads and room locations.

2. Establish the relationship between load magnitude and loaded area.

3. Determine load magnitudes for typical structural bay sizes and configurations.

4. Establish the characteristics of heavily loaded rooms.

The relationship between load magnitude and area and horizontal and vertical correlation of loads are particularly important since structural design requires design loads for structural bays rather than room loads and a knowledge of the variation of load through the height of the building. If room boundaries correspond to the framing system layout, the room data obtained in this survey can be used directly to establish structural bay loads. The data may also be used to obtain values for the more general situation where room boundaries and the framing system are not correlated. Using the floor plan layout for the buildings surveyed (6) and the load models developed in Section 3.8, loads could be calculated for the various rooms. After assuming loads for areas not included in the model (lavatories, corridors, etc.), the notional bay overlay concept used by Mitchell or an overlay of the exact framing system could then be used. An alternate approach would be to use Monte Carlo simulation techniques to construct floor plan layouts and framing system schemes, calculate the loads in the rooms using the load models in Section 3.8 and then calculate loads on the structural system using either the concept of tributary area or influence area (15) . As part of this analysis, horizontal and vertical correlation of loads would also be determined.

For each room surveyed, the computer program used for the data processing computed a variety of important quantities (6). Simulation studies similar to those in the appendix of this report could be carried out using these data. For example, the effect of enclosing all combustibles, such as paper and books, in metal containers could be evaluated by comparing the total fire loads presented herein with derated values obtained from such a study. The effect of changing the composition of office contents (replacing wood furniture by metal, etc.) could also be studied. Limited Monte Carlo simulation studies of this type to determine fire severity were carried out by Coward using existing survey data (16).

If additional survey work is done, the surveys should be carried out in Government buildings. This would reduce the problems of obtaining survey permission encountered in this survey. Based on results presented in Section 3.8, loads in Government and private office buildings do not differ significantly and the data obtained would be generally applicable. Also, since the geographic location of the building does not affect load magnitude, the survey work could be concentrated in one locality to minimize travel expenses for the survey crews. Data collected in the first phase should be used to plan these additional surveys. Correlations between the locations of rooms by room-use should be determined to establish a sampling plan for gathering data on horizontal and vertical correlation of loads. The characteristics of heavily loaded rooms could be determined to establish a sampling procedure to obtain data to better define the "tail" of the frequency distribution for load magnitude.

The survey forms, data collection procedures, and computer programs for data processing developed as part of this project could also be used to monitor the variation of loads with time. Periodically resurveying a particular building would indicate the types of load changes taking place and permit extrapolation for future requirements relative to live load and fire load capacity. Data could also be collected for use in planning renovation and rehabilitation work for existing buildings.

6. ACKNOWLEDGMENTS

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The field survey was carried out by Mathis Associates, Fresno, California, under the supervision of NBS staff. Professional staff from the J. H. Wiggins Co., Redondo Beach, California, developed the data reduction and analysis programs and participated in the analysis of the survey data. The assistance of Larry Lee, Joseph Hirschberg, and Jon Collins is particularly acknowledged. The Monte Carlo analysis of live load effects in the Appendix was carried out by Professor Gary Hart, University of California, Los Angeles, under the direction of the author. The assistance of Erne Wilkins, FOSDIC Branch, Engineering Division of the Bureau of the Census, was helpful in connection with the data processing.

The Building Owners and Managers Association cooperated in the project and Robert Wiggs, of BOMA, assisted in securing permission to survey a number of the buildings in the private sector. Survey permission for the government buildings was obtained through the Public Buildings Service, GSA.

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8. APPENDIX

STRUCTURAL INFLUENCE OF LIVE LOAD LOCATIONS

In order to simplify the data collection procedure in this survey, only approximate locations were obtained for the loads in the rooms, i.e. loads were recorded as to whether they were within two feet from the walls. An analysis of the effects of fire load location on fire severity and heat transferred to the bounding surfaces (floor, walls, ceiling) indicated that this approximate scheme was satisfactory (4). Studies of the influence of this procedure on the computation of forces in the structural system of a building indicated that the accuracy used to locate the loads in a room has an effect on the structural member forces computed from these loads (4). These studies were limited, however, and did not consider the full range of cases encountered in actual buildings. The analysis presented in this appendix is more general and is intended to evaluate the adequacy of the survey procedure from the standpoint of live load effects.

PROBLEM FORMULATION

Live loads in offices due to furniture, equipment, etc., will be arranged in various ways depending upon the configuration of the room, occupant preference and the nature of the work being conducted. The exact location of these items is of interest in planning work flow, movement of the occupants and other considerations relative to efficient space utilization. For structural design purposes, however, load locations are only important with respect to their effect on the structural system. The most appropriate way of evaluating these effects is through the use of influence surfaces (3, 5).

Recognizing that precise locations of office loads may not be required for structural design purposes, the approximate load location scheme shown in Figure A1 was adopted for the 1967 NBS load survey. Each office was subdivided into the nine sectors shown and the load for each item in the room assigned to one of the nine sectors. The dimensions of the strips were consistent with the definitions used in designing two-way flat slabs. It should be emphasized that the rationale used to establish this sector configuration assumes that the boundaries of the room correspond to the column lines for the structural system. This correlation has not been established and in many cases rooms in office buildings are smaller than structural bays. In other cases such as office landscaping, the rooms are larger than one structural bay.

Corotis' study of the adequacy of the sector arrangement in Figure A1 (2) and Yao's study of other sector arrangements (4) were limited to the case in which the room and structural bay were equal in size. For the study reported herein, a Monte Carlo simulation was carried out to evaluate the influence of various approximate load location schemes. The procedure followed was similar to that used by Corotis. Using influence surfaces, the forces and moments in the columns

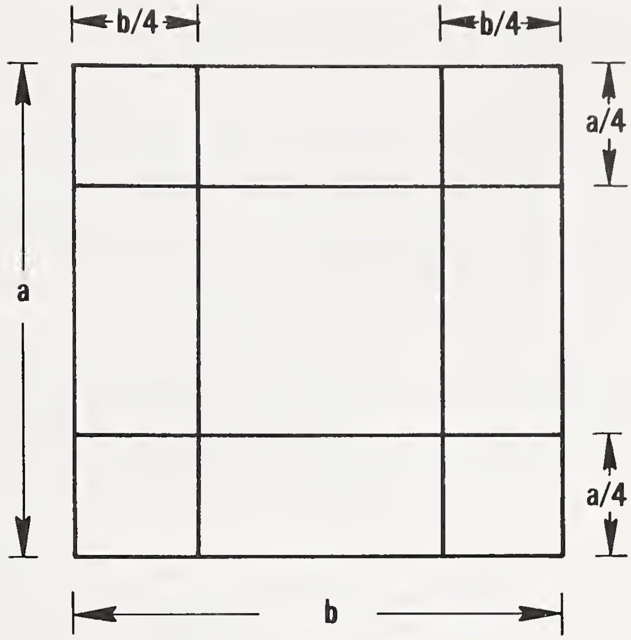

Figure A1 - Approximate Load Location Scheme
(1967 NBS Survey)

of the vertical load carrying system were determined using both the exact load locations and approximate locations. Whereas Corotis used only the survey data obtained from one building (2), this study includes a variety of parameters.

The room and bay configurations adopted are shown in Figure A2. The four columns represent a structural bay. Forces and moments in all cases were computed for column 1. Two cases were considered for the room location. For Case I one corner of the room coincided with a corner of the structural bay. For Case II the room was located in the center of the bay. In each case the room dimensions were taken as a percentage of the bay dimensions. The limiting case involved a room equal in size to the structural bay. The case of a room larger than a structural bay was not considered.

Four different schemes were used for subdividing a room. These are shown in Figure A3 and will be referred to as the one-sector, two-sector, five-sector, and nine-sector model. The nine-sector model is the one used in the 1967 NBS survey and the two-sector model the one adopted in the current survey, i.e. in the current survey load locations are only recorded as either being within 2 feet of the wall or greater than 2 feet from the wall.

The number of loads, load magnitude, and the location of the loads in a room were varied over a wide range. This was done in order to investigate the significance of various load arrangements as opposed to using limited survey data. The number of loads was treated as a random variable with a normal probability density function. Most previous surveys have not reported values for this quantity. Data from the 1967 NBS survey indicated an average of nine loads per room and Corotis' studies were based on this value. Only loads corresponding to heavy furniture items (desks, tables, etc.) were considered and loads due to chairs, wastebaskets, etc. were neglected. The majority of rooms in that survey, however, were between 150 feet^2 and 200 feet^2. For larger rooms one would expect a larger number of loads. The current survey indicated that a typical room contained more than nine discrete loads. For the case of a room equal in size to a structural bay a mean value of sixteen loads was used. The case of thirty-two loads was also considered to determine the effect of this parameter. For a smaller room with an area equal to approximately one-half the area of the structural bay, mean values of eight and sixteen loads were considered. Since the current survey data indicated considerable scatter, a coefficient of variation of 50 percent was used.

Load magnitude was also treated as a random variable. The 1967 NBS survey data indicated that the load per unit area on the individual sectors could be represented by a series of gamma probability distributions (2). The probability distribution of the load per unit area for a complete room, however, was approximately normal. Mitchell's data (6) indicated a similar trend. A normal distribution was used, therefore, for the load magnitude in this study. A log normal distribution was also considered to evaluate the effect of this parameter. Data on individual load magnitudes were not given in previous studies. Corotis used a mean value of 245 lb. and a standard deviation of 80 lb. In this study

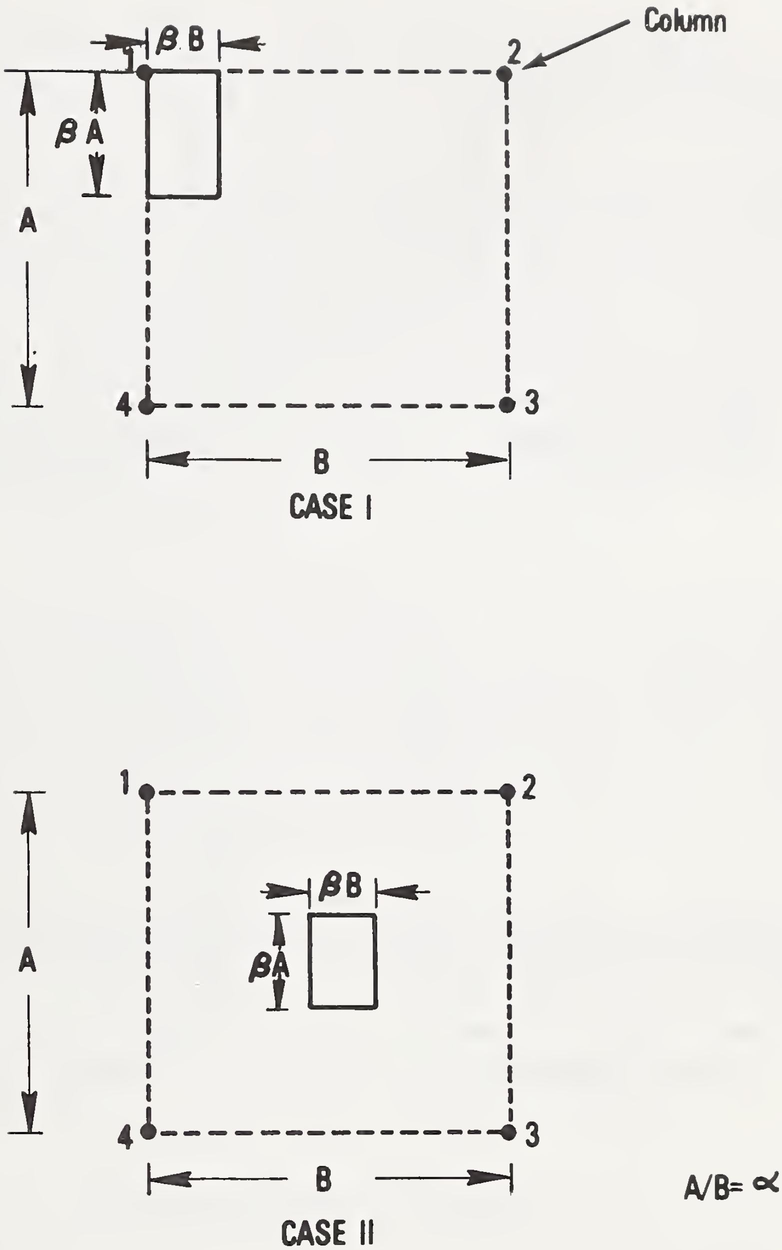

Figure A2 - Room and Bay Configurations

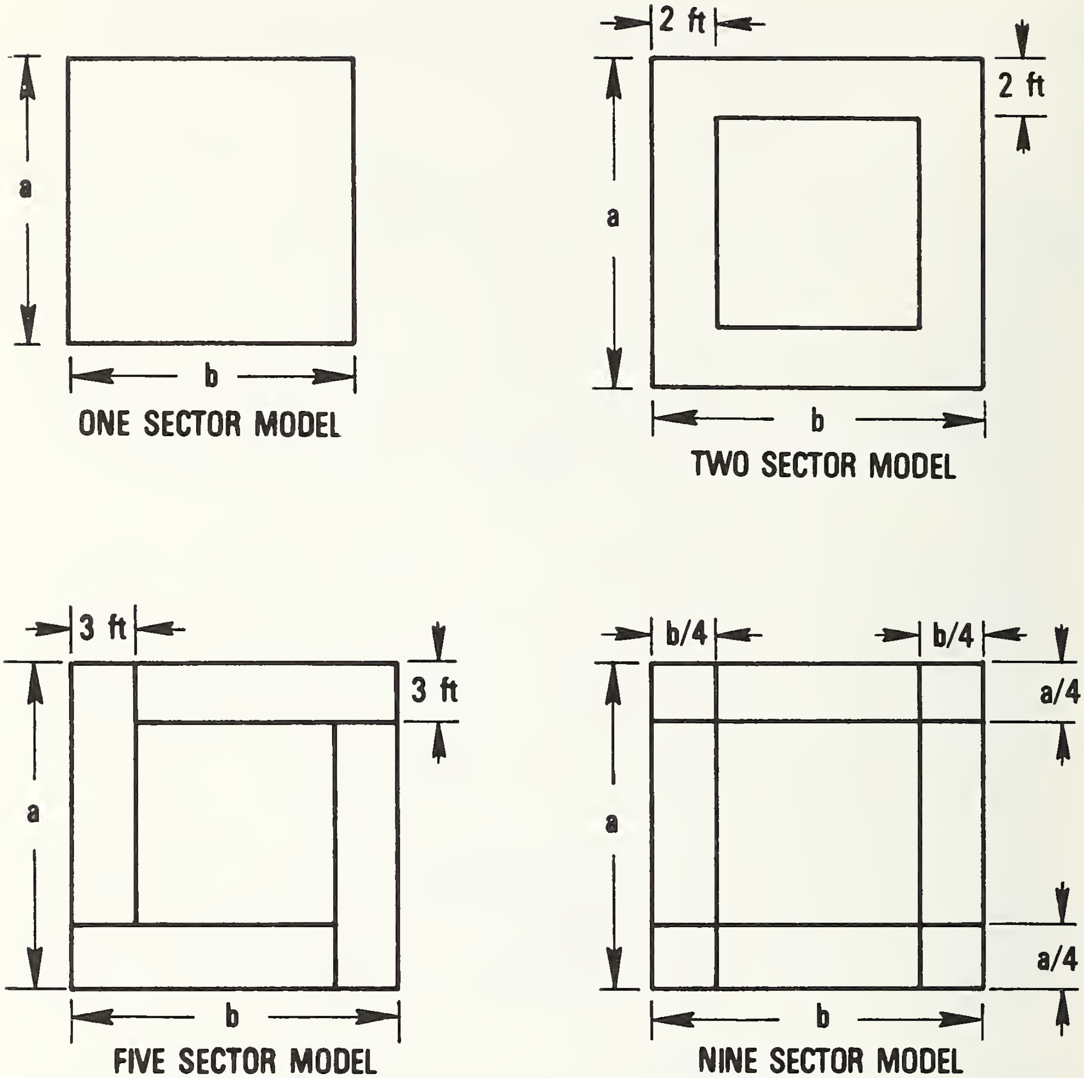

Figure A3 - Sector Models Studied

a mean value of 100 lb. was used since all the items in a room were considered. Since the data showed considerable scatter with loads as low as 5-10 lb. (wastebaskets) and as high as several hundred pounds for heavy furniture, a coefficient of variation of 50 percent was used. A value of 150 percent was also used for the coefficient of variation.

The location of the loads in the room was also treated as a random variable. A uniform distribution of loads throughout the room was used with the expected value of the number of loads in each sector being the same. This corresponded to the case studied by Corotis (2). Since the current survey indicated a tendency for discrete loads to be located around the perimeter of the room, particularly for smaller rooms, a second case with 70 percent of the discrete loads around the perimeter and 30 percent in the center portion of the room was also studied. The placement of loads was random and a uniform distribution throughout each portion was used. Since the discrete loads used represent the load at the center of gravity of the furniture item, a constraint was required to represent the practical case with a finite spacing between items. In all cases, the location of each load relative to the other loads and the boundaries of the room was constrained to be greater than two feet. This minimum value was based on the "average" size of office furniture.

The effects of the variables noted on the axial force and moments for Column 1 in Figure A2 were studied using influence surfaces. The forces were computed using the influence ordinate for each load location and also using the average influence ordinate for the various sectors for all loads in that sector. The same approximate influence surfaces as used by Corotis (3) and Peir (7) were used in this study. The difference between the forces computed using the exact and approximate locations provides an indication of the "error" associated with using subdivisions for a room as opposed to exact load locations (3). Since the ratio of these forces or the percent difference provides a better indication of the relative error than simply the difference, results presented in the next section are expressed in this form.

A special computer program was written to carry out this study. The program was written to allow considerable flexibility in order to investigate a variety of combinations of room and bay proportions, number of loads, load magnitude, and load location.

NUMERICAL RESULTS

The computer program was first used to solve Corotis' and compare the results with those from the closed form solution. This comparison is given in Table 1 for column axial load and column moments. For this problem the room was equal in size to the bay and there were exactly nine loads. The mean value and coefficient of variation were the same as those used by Corotis (2). A normal distribution was assumed for load magnitude in the Monte Carlo solution. The closed form solution of Corotis was independent of this parameter and utilized only the mean and standard deviation. A uniform probability of occurrence was used for the position of the nine loads throughout the room. The ratio of the mean column load computed using the nine-sector model and the exact load location is given. Since no attempt was made to determine the probability density function for this ratio, the interval (X_1, X_2) for which the probability that the error in the computed column load due to using sectors is less than some value α, $P[X_1 \leq P_S/P_E \leq X_2] = 1 - \alpha$, was not determined. To provide a qualitative estimate for other than the mean error, the column load ratio using the exact and approximate load locations was computed for one, two and three standard deviations.

Referring to Table 1, the ratio for the mean column load for the two solutions differs by only one percent. The difference for the moment ratio is slightly higher. The two moment ratios for the Monte Carlo solution correspond to the moments about the x and y axes, respectively. Only the moment about the y axis was computed by Corotis. As the number of standard deviations increases, the difference between the column loads obtained using sectors versus the exact load location increases for both solutions. The differences between the two solutions also increases with the maximum difference being 12 percent for the moment about the x axis at three standard deviations.

The influence of the number and distribution of the loads in the room on the column load and moment ratios are presented in Table 2. The single ratio given for moments corresponds to the worst case, i.e. the lowest ratio. Sixteen and thirty-two loads were used with a uniform probability for the load location. Since the survey results indicated that the furniture in rooms is usually located around the perimeter, the case with seventy percent of the loads around the perimeter and the remaining thirty percent in the center portion was also studied. For all the cases in Table 2, the error in the mean column load is less than one percent. The influence of the number of sectors does affect the mean column moment but the differences are not significant from the practical standpoint. For axial load, the results obtained for one and two sectors were the same. The error increases with the number of standard deviations. For sixteen loads the ratio decreases from 0.871 at one standard deviation to 0.729 at three standard deviations. As expected, the error decreases as the number of sectors is increased. The maximum error for the two-sector model at three standard deviations is 27 percent and 5 percent for the nine-sector model. Comparing the results for 16 and 32 loads indicates that the error decreases as the number of loads increases.

TABLE 1 COMPARISON OF RESULTS FOR MONTE CARLO AND CLOSED FORM SOLUTION
(Room Equal to Bay)

Aspect Ratio of Bay - 1
Number of Loads - $m = 9$, $\nu = 0$
Load Distribution - Uniform
Load Magnitude - Normal Distribution, $m = 245$ lb., $\nu = 0.33$
Number of Sectors - 9

	Axial Load				Column Moment			
	$\frac{P_S}{P_E}$	$\frac{P_S + s}{P_E + s}$	$\frac{P_S + 2s}{P_E + 2s}$	$\frac{P_S + 3s}{P_E + 3s}$	$\frac{M_S}{M_E}$	$\frac{M_S + s}{M_E + s}$	$\frac{M_S + 2s}{M_E + 2s}$	$\frac{M_S + 3s}{M_E + 3s}$
Closed Form Solution (Ref. 2)	1.00	0.990	0.985	0.983	1.00	0.991	0.987	0.984
Monte Carlo Solution	1.01	0.978	0.958	0.945	0.971 0.980	0.915 0.952	0.883 0.935	0.862 0.925

TABLE 2 INFLUENCE OF NUMBER OF LOADS
(Room Equal to Bay)

Aspect Ratio of Bay - 1
Load Magnitude - Normal Distribution, m = 100 lb., ν = 0.5

No. of Loads*	Load Distribution	No. of Sectors	Axial Load				Column Moment			
			$\frac{P_S}{P_E}$	$\frac{P_S + s}{P_E + s}$	$\frac{P_S + 2s}{P_E + 2s}$	$\frac{P_S + 3s}{P_E + 3s}$	$\frac{M_S}{M_E}$	$\frac{M_S + s}{M_E + s}$	$\frac{M_S + 2s}{M_E + 2s}$	$\frac{M_S + 3s}{M_E + 3s}$
16	Uniform	1	1.008	0.871	0.786	0.729	1.012	0.885	0.806	0.752
		2	1.008	0.871	0.786	0.729	0.957	0.851	0.781	0.734
		5	0.997	0.915	0.864	0.830	0.947	0.878	0.834	0.803
		9	1.002	0.976	0.959	0.948	0.956	0.914	0.888	0.869
32	Uniform	1	1.010	0.931	0.873	0.828	1.009	0.934	0.879	0.837
		2	1.010	0.931	0.873	0.828	0.954	0.890	0.842	0.805
		5	0.999	0.961	0.933	0.912	0.952	0.919	0.893	0.872
		9	0.996	0.989	0.984	0.980	0.955	0.943	0.934	0.927
16	70% around perimeter	1	1.021	0.927	0.871	0.834	1.266	1.140	1.067	0.977
		2	1.021	0.927	0.871	0.834	0.943	0.866	0.820	0.790
		5	0.992	0.931	0.894	0.870	0.983	0.919	0.881	0.856
		9	0.995	0.978	0.969	0.962	1.068	0.987	0.959	0.940
32	70% around perimeter	1	0.990	0.914	0.868	0.836	1.212	1.127	1.075	0.940
		2	0.990	0.914	0.868	0.836	0.923	0.848	0.804	0.775
		5	0.998	0.948	0.917	0.896	1.005	0.945	0.914	0.893
		9	0.997	0.979	0.968	0.961	1.053	1.005	0.979	0.962

*ν = 0.0 for uniform load distribution and 0.4 for 70% around perimeter

The load distribution also affects the error. For 16 loads the error is less for the case of 70 percent of the load around the perimeter than for a uniform distribution. The decrease due to this effect is less significant for 32 loads.

For column moments in Table 2, the error for the mean is greater than for axial loads. Unlike the case for axial load, the results for one and two sectors are different. The mean is also more sensitive to the number of sectors. For one, two and three standard deviations, however, the number of sectors is less significant. For example, with 16 loads and a uniform distribution the axial load ratio at three standard deviations changed from 0.729 for one sector to 0.948 for nine sectors (30 percent) while the moment ratio only changed by 16 percent from 0.752 to 0.869. As with axial load, the error increases with the number of standard deviations. Note that in some cases, however, the ratio is greater than one indicating that the moments obtained using sectors would be greater than those obtained from the exact load location. As with axial load, the errors decrease for the case of 70 percent of the loads around the perimeter.

The influence of room size is indicated in Table 3. For this case the room dimensions were 75 percent of the bay dimensions, i.e. the room area was 56 percent of the bay area. The room was located in the corner of the bay, Figure A2-Case I. This corresponds more closely to the situation in office buildings since the mean room area for the offices surveyed was approximately 200 ft^2 and common structural bay sizes are around 400-600 ft^2. The load distribution and magnitude were the same as those used in Table 2. The number of loads was reduced, however, for this smaller room since the survey data indicated the mean number of loads in a room this size was 18. The results in Table 3 are similar to those in Table 2 and the same trends occur. The errors for this case are much less, however. For 16 loads and a uniform load distribution, the axial load ratio for one sector at three standard deviations was 0.729 in Table 2. This ratio increased to 0.878 in Table 3. The errors occurring as a result of using sectors is thus directly related to the size of the room relative to the structural bay. For the case encountered in this survey (16 loads, 70% around perimeter, room area   bay area/2), the maximum axial load and moment error for the two-sector model is 7 percent. This error is negligible from the practical point of view when one considers inherent measurement errors in any survey technique and the fact that furniture loads are not single concentrated loads.

The influence of room location is shown by comparing Table 3 to Table 4. The parameters used were the same as those for Table 3 except that the room is located in the center of the structural bay. The error associated with using sectors is greater in this case than for the room in the corner of the bay. For 16 loads, uniform distribution and three standard deviations, the axial load ratio changed from 0.878 in Table 3 to 0.799 in Table 4. This is as expected since the column load influence surface gradient is steeper near the middle of the bay than near the corner and consequently calculations of the column load are more sensitive to the position of loads in the room. For the

TABLE 3 INFLUENCE OF NUMBER OF LOADS
(Room Area Equal to Approximately One-half Bay Area-Corner)

Aspect Ratio of Bay - 1
Load Magnitude - Normal Distribution, m = 100 lb., ν = 0.5

No. of Loads*	Load Distribution	No. of Sectors	Axial Load				Column Moment			
			$\frac{P_S}{P_E}$	$\frac{P_S + s}{P_E + s}$	$\frac{P_S + 2s}{P_E + 2s}$	$\frac{P_S + 3s}{P_E + 3s}$	$\frac{M_S}{M_E}$	$\frac{M_S + s}{M_E + s}$	$\frac{M_S + 2s}{M_E + 2s}$	$\frac{M_S + 3s}{M_E + 3s}$
8	Uniform	1	0.982	0.910	0.863	0.830	0.958	0.901	0.862	0.835
		2	0.978	0.908	0.862	0.830	0.902	0.868	0.845	0.829
		5	0.986	0.964	0.949	0.939	0.931	0.910	0.896	0.886
		9	0.980	0.968	0.960	0.955	0.946	0.939	0.930	0.918
16	Uniform	1	0.999	0.946	0.907	0.878	1.005	0.937	0.890	0.854
		2	0.996	0.945	0.907	0.878	0.952	0.900	0.863	0.834
		5	0.999	0.973	0.953	0.938	0.955	0.934	0.918	0.907
		9	0.996	0.988	0.982	0.978	0.960	0.945	0.935	0.927
8	70% around perimeter	1	1.017	0.990	0.973	0.962	1.160	1.124	1.102	1.049
		2	0.995	0.967	0.949	0.938	0.961	0.936	0.920	0.909
		5	0.992	0.973	0.961	0.953	0.961	0.961	0.945	0.935
		9	1.016	1.008	1.003	1.000	1.019	1.001	0.990	0.982
16	70% around perimeter	1	1.028	0.988	0.962	0.944	1.144	1.096	1.065	1.043
		2	1.006	0.968	0.944	0.927	0.976	0.959	0.945	0.931
		5	1.005	0.988	0.976	0.968	0.959	0.961	0.958	0.953
		9	1.014	1.006	1.000	0.996	1.008	0.982	0.970	0.962

*ν = 0.0 for uniform load distribution and 0.4 for 70% around perimeter

TABLE 4 INFLUENCE OF NUMBER OF LOADS
(Room Area Equal to Approximately One-half Bay Area-Center)

Aspect Ratio of Bay - 1
Load Magnitude - Normal Distribution, m = 100 lb., ν = 0.5

No. of Loads*	Load Distribution	No. of Sectors	Axial Load				Column Moment			
			$\frac{P_S}{P_E}$	$\frac{P_S + s}{P_E + s}$	$\frac{P_S + 2s}{P_E + 2s}$	$\frac{P_S + 3s}{P_E + 3s}$	$\frac{M_S}{M_E}$	$\frac{M_S + s}{M_E + s}$	$\frac{M_S + 2s}{M_E + 2s}$	$\frac{M_S + 3s}{M_E + 3s}$
8	Uniform	1	0.970	0.847	0.774	0.726	0.956	0.862	0.804	0.764
		2	0.970	0.847	0.774	0.726	0.919	0.836	0.783	0.748
		5	0.978	0.937	0.912	0.896	0.940	0.914	0.898	0.881
		9	0.965	0.951	0.943	0.937	0.941	0.925	0.915	0.908
16	Uniform	1	0.998	0.907	0.845	0.799	1.000	0.919	0.862	0.820
		2	0.998	0.907	0.845	0.799	0.966	0.891	0.838	0.799
		5	1.000	0.953	0.921	0.898	0.968	0.934	0.910	0.892
		9	0.994	0.982	0.974	0.968	0.967	0.952	0.941	0.933
8	70% around perimeter	1	0.978	0.915	0.879	0.855	1.066	0.983	0.953	0.934
		2	0.978	0.915	0.879	0.855	0.956	0.906	0.877	0.858
		5	0.976	0.934	0.910	0.895	0.957	0.931	0.916	0.906
		9	1.003	0.990	0.983	0.978	0.992	0.980	0.971	0.963
16	70% around perimeter	1	0.999	0.929	0.887	0.858	1.068	1.003	0.962	0.934
		2	0.999	0.929	0.887	0.858	0.978	0.932	0.896	0.872
		5	1.003	0.967	0.946	0.931	0.973	0.954	0.942	0.933
		9	1.006	0.994	0.986	0.981	0.992	0.973	0.962	0.954

*ν = 0.0 for uniform load distribution and 0.4 for 70% around perimeter

practical case of 16 loads with 70 percent located around the perimeter, the column load error at three standard deviations is 16 percent for two sectors versus only two percent for nine sectors. The results in Table 3 and 4 indicate that errors in structural load effects associated with the use of sectors are sensitive to the location of the room relative to the structural framing system.

The influence of the manner in which the loads are distributed in the room is illustrated in Table 5. Results for the uniform distribution and 70 percent around the perimeter were presented earlier in Table 2. An additional case in which most of the load is in the center portion (30 percent around perimeter) was also considered. The errors for the cases with 70 and 30 percent around the perimeter are much less than for the uniform distribution. The error due to using sectors does not appear to be sensitive to the load distribution in the room for practical distributions, i.e. for load distributions other than uniform. The results using a lognormal distribution for load magnitude are similar to those for the normal distribution. Errors due to using sectors do not appear to be sensitive to the form of the load magnitude frequency distribution.

The results in Table 6 for the case in which the area of the room is approximately half the area of the bay are similar to those in Table 5. In this case the errors are less sensitive to the load distribution.

The influence of the variability of load magnitude is indicated in Table 7. Using a normal distribution for the load magnitude, coefficients of variation of 0.5 and 1.5 were considered. In each case the error due to using sectors decreased as the variability increased. For example, the column load error at three standard deviations for one sector decreased from 0.729 to 0.774 for the room equal in size to the structural bay.

CONCLUSIONS

The results presented herein indicate that errors in structural load effects computed using approximate load locations (sectors) are sensitive to the distribution of the loads in the room, the size of the room relative to the structural bay and the location of the room relative to the structural framing system. The errors occurred primarily in the standard deviation and mean values for the structural loads were not significantly affected. The error for column moments is more sensitive than the axial load error. The influence of the number of loads and the form of the load magnitude frequency distribution was less significant. In most cases, the column load error decreased as the number of sectors increased. The error in column moment was more erratic and in some cases increased as the number of sectors increased. For nine sectors, the error in the column load was less than six percent in all cases considered. The maximum error at three standard deviations in column moment for nine sectors was 13 percent. For five sectors the maximum errors at three standard deviations in column load and moment were 17 percent and 20 percent respectively. The maximum errors at three standard deviations for two sectors were 27 percent.

TABLE 5 INFLUENCE OF LOAD DISTRIBUTION
(Room Equal to Bay)

Aspect Ratio of Bay - 1
Number of Loads - m = 16, ν = 0.0 for uniform load distribution and 0.4 for 70% and 30% around perimeter
Load Magnitude - Normal Distribution, m = 100 lb., ν = 0.5

Load Distribution	No. of Sectors	Axial Load				Column Moment			
		$\frac{P_S}{P_E}$	$\frac{P_S + s}{P_E + s}$	$\frac{P_S + 2s}{P_E + 2s}$	$\frac{P_S + 3s}{P_E + 3s}$	$\frac{M_S}{M_E}$	$\frac{M_S + s}{M_E + s}$	$\frac{M_S + 2s}{M_E + 2s}$	$\frac{M_S + 3s}{M_E + 3s}$
Uniform	1	1.008	0.871	0.786	0.729	1.012	0.885	0.806	0.752
	2	1.008	0.871	0.786	0.729	0.957	0.851	0.781	0.734
	5	0.997	0.915	0.864	0.830	0.947	0.878	0.834	0.803
	9	1.002	0.976	0.959	0.948	0.956	0.914	0.888	0.869
70% around perimeter	1	1.021	0.927	0.871	0.834	1.266	1.140	1.067	0.977
	2	1.021	0.927	0.871	0.834	0.943	0.866	0.820	0.790
	5	0.992	0.931	0.894	0.870	0.983	0.919	0.881	0.856
	9	0.995	0.978	0.969	0.962	1.068	0.987	0.959	0.940
30% around perimeter	1	0.978	0.928	0.899	0.881	0.952	0.892	0.857	0.835
	2	0.978	0.928	0.899	0.881	0.939	0.904	0.884	0.872
	5	0.995	0.948	0.921	0.904	0.938	0.916	0.894	0.881
	9	0.996	0.970	0.955	0.945	0.929	0.900	0.883	0.873
Uniform*	1	1.016	0.883	0.802	0.748	1.021	0.898	0.821	0.770
	2	1.016	0.883	0.802	0.748	0.962	0.858	0.790	0.744
	5	0.999	0.919	0.870	0.837	0.950	0.881	0.839	0.809
	9	1.001	0.971	0.953	0.941	0.956	0.910	0.882	0.863

*Load Magnitude - Lognormal Distribution

TABLE 6 INFLUENCE OF LOAD DISTRIBUTION
(Room Area Equal to Approximately One-half Bay-Corner)

Aspect Ratio of Bay - 1
Number of Loads - m = 16, ν = 0.0 for uniform load distribution and 0.4 for 70% and 30% around perimeter
Load Magnitude - Normal Distribution, m = 100 lb., ν = 0.5

Load Distribution	No. of Sectors	Axial Load				Column Moment			
		$\frac{P_S}{P_E}$	$\frac{P_S + s}{P_E + s}$	$\frac{P_S + 2s}{P_E + 2s}$	$\frac{P_S + 3s}{P_E + 3s}$	$\frac{M_S}{M_E}$	$\frac{M_S + s}{M_E + s}$	$\frac{M_S + 2s}{M_E + 2s}$	$\frac{M_S + 3s}{M_E + 3s}$
Uniform	1	0.999	0.946	0.907	0.878	1.005	0.937	0.890	0.854
	2	0.996	0.945	0.907	0.878	0.952	0.900	0.863	0.834
	5	0.999	0.973	0.953	0.938	0.955	0.934	0.918	0.907
	9	0.996	0.988	0.982	0.978	0.960	0.945	0.935	0.927
70% around perimeter	1	1.028	0.988	0.962	0.944	1.144	1.096	1.065	1.043
	2	1.006	0.968	0.944	0.927	0.976	0.959	0.945	0.931
	5	1.005	0.988	0.976	0.968	0.959	0.961	0.958	0.953
	9	1.014	1.006	1.000	0.996	1.008	0.982	0.970	0.962
30% around perimeter	1	1.005	0.988	0.978	0.971	0.951	0.923	0.903	0.889
	2	1.017	1.005	0.998	0.993	0.959	0.951	0.942	0.937
	5	1.007	1.008	1.009	1.009	0.965	0.961	0.958	0.957
	9	0.998	0.999	1.000	1.001	0.939	0.931	0.927	0.924
Uniform*	1	0.999	0.948	0.911	0.882	1.004	0.933	0.886	0.851
	2	0.997	0.947	0.910	0.882	0.950	0.896	0.858	0.830
	5	1.001	0.975	0.957	0.943	0.954	0.933	0.918	0.907
	9	0.996	0.988	0.983	0.978	0.960	0.947	0.938	0.931

*Load Magnitude - Lognormal Distribution

TABLE 7 INFLUENCE OF VARIABILITY IN LOAD MAGNITUDE

Aspect Ratio of Bay - 1
Number of Loads - m = 16, ν = 0.5
Load Distribution - Uniform
Load Magnitude - Normal Distribution, m = 100 lb.

Room Size	Load Magnitude ν	No. of Sectors	Axial Load				Column Moment			
			$\frac{P_S}{P_E}$	$\frac{P_S + s}{P_E + s}$	$\frac{P_S + 2s}{P_E + 2s}$	$\frac{P_S + 3s}{P_E + 3s}$	$\frac{M_S}{M_E}$	$\frac{M_S + s}{M_E + s}$	$\frac{M_S + 2s}{M_E + 2s}$	$\frac{M_S + 3s}{M_E + 3s}$
Equal to Bay	0.5	1	1.008	0.871	0.786	0.729	1.012	0.885	0.806	0.752
		2	1.008	0.871	0.786	0.729	0.957	0.851	0.781	0.734
		5	0.997	0.915	0.864	0.830	0.947	0.878	0.834	0.803
		9	1.002	0.976	0.959	0.948	0.956	0.914	0.888	0.869
	1.5	1	1.026	0.888	0.817	0.774	1.025	0.896	0.829	0.788
		2	1.026	0.888	0.817	0.774	0.966	0.849	0.788	0.750
		5	1.002	0.917	0.874	0.847	0.940	0.871	0.836	0.814
		9	1.006	0.979	0.964	0.956	0.962	0.915	0.891	0.876
≈ 1/2 Bay Area-Corner	0.5	1	0.999	0.946	0.907	0.878	1.005	0.937	0.890	0.854
		2	0.996	0.945	0.907	0.878	0.952	0.900	0.863	0.834
		5	0.999	0.973	0.953	0.938	0.955	0.934	0.918	0.907
		9	0.996	0.988	0.982	0.978	0.960	0.945	0.935	0.927
	1.5	1	1.002	0.950	0.917	0.895	1.011	0.934	0.894	0.867
		2	1.000	0.950	0.918	0.896	0.951	0.899	0.867	0.846
		5	1.006	0.981	0.966	0.955	0.958	0.940	0.929	0.922
		9	0.997	0.983	0.974	0.968	0.959	0.940	0.929	0.921
≈ 1/2 Bay Area-Center	0.5	1	0.998	0.907	0.845	0.799	1.000	0.919	0.862	0.820
		2	0.998	0.907	0.845	0.799	0.966	0.891	0.838	0.799
		5	1.000	0.953	0.921	0.898	0.968	0.934	0.910	0.892
		9	0.994	0.982	0.974	0.968	0.967	0.952	0.940	0.933
	1.5	1	1.005	0.912	0.859	0.824	1.008	0.919	0.870	0.838
		2	1.005	0.912	0.859	0.824	0.969	0.893	0.847	0.818
		5	1.011	0.963	0.934	0.916	0.976	0.942	0.922	0.909
		9	0.996	0.976	0.964	0.957	0.968	0.945	0.932	0.923

It is clear that column loads computed using survey data in which the load locations are determined approximately will be less than those computed using exact load locations. Using two, five, or nine sectors the errors for the mean column load and moment should be less than three percent and ten percent, respectively. For extreme values (mean plus N standard deviations) these errors will increase. Since the errors associated with sectors are related to the size of the room relative to the structural bay and the location of the room relative to the framing system, it would be advisable to record the location of the framing system in such surveys to assess the relative errors. The computer program employed herein could then be used to assess the error and possibly develop appropriate correction factors to account for this effect.

The following symbols are used in this appendix:

- a = width of structural bay;
- b = length of structural bay;
- i = number of sectors;
- m = mean value;
- M_E = column moment using exact load location;
- M_{Si} = column moment using i sectors;
- N = number of discrete loads;
- P_E = column load using exact load location;
- P_{Si} = column load using i sectors;
- s = standard deviation;
- v = coefficient variation;
- α = aspect ratio for structural bay, a/b; and
- β = ratio of room dimensions to bay dimensions.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Fire load and live load data obtained from a survey of 23 office buildings located in various regions throughout the United States are presented. The survey design is described including the characteristics of the building population used to select the sample. Data are presented on the magnitude and distribution of the loads. Information is also included on the characteristics of office loads such as the type of items (furniture, equipment, etc.) and their properties (material type, dimensions exposure, etc). Statistical summaries of the data and a determination of the building and occupancy characteristics affecting these loads are presented. The data do not indicate any significant differences between the loads in private and government buildings. Similarly, geographic location, building height, and building age were not found to have a significant influence on load magnitude. The use of the rooms surveyed, however, did affect load magnitude. A mathematical model developed from a regression analysis of the survey data is presented for calculating fire loads and live loads in offices. The data presented may be used to evaluate current requirements for design loads for buildings.

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