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A Literature Review of Fire and Live Load Surveys in Residences

Lionel A. Issen

Center for Fire Research
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

May 1978

Final Report

Sponsored in part by:

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U.S. DEPARTMENT OF COMMERCE

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Lionel A. Issen

Abstract

A search of the literature shows that most load surveys have been concerned with commercial and industrial occupancies and only a few have dealt with residences. Many surveys have been inadequately reported from a statistical viewpoint, and the data have been misapplied. A common error has been to assume that the largest observed load is the largest expected load. The statistics of extremes should be used to determine reasonable design values. Methods for estimating the sampling size (for a prescribed accuracy) are given and illustrated with examples.

Key words: Design loads; fire; fire loads; household surveys; live loads; residential surveys; statistics of extremes.

1. INTRODUCTION

Load surveys have always interested structural engineers and their predecessors, the master builders. An examination of older structures and documents indicates that the master builders of the past must have understood, even if only intuitively or empirically, the connection between loads, forces in members, and structural sizes. This kind of understanding implies a knowledge of the loads produced by different furnishings and other load items.

The main source for historical data was Heaney's thesis [1][1]. A second source for information on load surveys and related literature was the bibliography in the paper by Culver and Kushner [2]. The oldest reported load survey that Heaney [1] uncovered was carried out by Stoney in 1869. It was concerned principally with the maximum load produced by people in assembly areas. The oldest residential survey found was made by Aus in New York in 1904.

Heaney [1] lists 59 published load surveys. Only eight of these were classed as "domestic dwellings." Of these eight, only Ingberg's survey [3] considered fire loads. The others were only concerned with the live loads. This report provides a guide to the literature on residential load surveys and discusses (1) their planning and conduct,

[1] Numbers in brackets refer to the literature references listed at the end of this paper.

(2) the limitations on the use of the data, and (3) newer methods of analysis.

2. APPLICATION OF SURVEY DATA

2.1 Classification of Loads

In the past it appears that load survey data have been misapplied by misunderstanding both the data from the load survey and the effect of all the load producing actions on the structure. The main errors are the assumption that the maximum observed load is the same as the maximum expected load, and that the average or some cumulative percentile of the observed loads may be directly extrapolated to a design load. The former is in error because the maximum observed load may differ significantly from the maximum expected load [1,3] and the latter ignores impact, tolerable levels of vibration, long term deflections and short term heavy loads.

Impact and vibrating loads which may be produced by wind gusts, moving furniture, running children, passing vehicles, etc., may cause unpleasant vibrations to the occupants of a residence.

Long term loads, such as those produced by heavier items (semi-permanent partitions, heavy furniture, pianos, fish tanks, water beds, heavy appliances) may produce excessive long term permanent deflections in the structure.

Short term heavy loads may be produced in residences when the house is being redecorated and the furnishings from several rooms are stored in one room or when parties or meetings are held.

Thus, any recommendations for design loads which may be imbedded in codes and design manuals should include impact, long term deflections, and short term overloading. Analogous considerations should also be applied to fire loads.

2.2 Statistical Weaknesses of Load Survey Data

A great weakness of most load surveys, particularly those made prior to 1960 is that they did not make adequate use of statistical analysis. This is not to suggest that very sophisticated statistical analyses are always necessary. However, mean, standard deviation, confidence limits, estimates of required sample size to achieve desired levels of accuracy, probability distribution functions of the observed loadings, and analysis of the probability of extreme loads would improve the value and usefulness of the surveys. Hasofer [4] has stated, "The published results of past surveys are unfortunately not given in a suitable form (for analysis). The main methodological mistake was the statistical misconception that one can obtain a reasonable picture of possible maxima of loads by looking at the observed maxima of the survey. The statistical theory of extreme values has shown that this is an unreliable and inefficient method of analysis."

3. INGBERG'S RESIDENTIAL FIRE LOAD SURVEY

Ingberg's survey [3] had been preceded by a series of burnout tests of office type occupancies that extended over a decade. From these tests Inberg [5] had developed a method for relating the actual temperatures measured in a fire produced by a known fire load to an equivalent standard ASTM E-119 [6] fire test exposure. This method which was extended in 1939 to include burnouts of residential occupancies [7] was based on comparing equivalent areas under the temperature-time curve for the experimental fire with that from a standard ASTM E-119 test.

Ingberg surveyed 13 residential occupancies (apartments and single-family homes), which included 1 basement, 10 bathrooms, 18 bedrooms and closets combined, 3 dining rooms, 12 hallways, 11 kitchens, 1 library, 13 living rooms, 6 storerooms (in apartments), 1 vestibule. These data are shown in table 1. The survey provided information on fire loads which could be used to estimate the fire endurance that should be provided by the compartment walls and floor/ceiling.

The data in BMS 92 [3] and a subsequent publication BMS 149 [8] represented the first effort to describe the fire load in a variety of occupancies. Though the data in BMS 92 from a statistical viewpoint constitutes a small sample, they have continued to be of interest to design engineers and regulatory officials. In 1976 BMS 92 was reissued to meet the continued demand for it. At this time we know that it is not adequate to use a single method to relate fire load[2] and required fire resistance[3]. Other factors such as the interior finish, the nature of the materials and the ventilation are also important in determining the equivalent fire exposure. Harmathy and Lie [9] and others have pointed out that it is inadequate to estimate equivalent fire exposure times by equating equivalent areas under a time temperature curve as Ingberg did in developing his equivalent fire load concept [5,7]. Harmathy and Lie have also shown that the maximum temperature as well as duration of temperature controls the structural behavior of assemblies in a fire.

Notwithstanding these modern developments and limitations, Ingberg's approach has been used for many years for estimating required fire endurances. It should be noted that Ingberg [5] clearly understood the approximations involved in his equivalent fire load concept.

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[2] Fire load is usually defined as the unit floor load of combustibles in terms of a standard material, usually wood.

[3] Fire resistance is the time that a building element withstands the ASTM E-119 test usually expressed in hours.

Table 1. Summary Data for Apartments and Residences (Ingberg's Survey) [3]

Survey No.	Floor area	Combustible Contents			
		Movable property	Floor	Exposed woodwork other than floor	Total
Entire apartment or residence					
	ft^2	lb/ft^2	lb/ft^2	lb/ft^2	lb/ft^2
A-1	695	3.1	3	3.6	9.7
A-2	670.5	2.5	3	2.8	8.2
A-3	544	2.4	2.7	3.4	8.5
A-4	604.5	2.7	3	2.6	8.2
A-6	519	3.4	3	2.9	9.3
A-7	647	4.0	3	2.7	9.7
A-8	431	3.4	3	3.6	10
A-9	514	3.5	3	2.9	9.4
A-10.......	734	3.7	1.9	2.9	8.5
A-11.......	734	2.9	1.9	2.8	7.6
A-12.......	748	4.9	0	2.7	7.6
A-13.......	529	4.6	3	1.5	9.1
A-17.......	796	3.1	3	2.2	8.3
Average..	....	3.4	2.6	2.8	8.8
Basement					
A-1........	783	0.8	0.0	0.2	1.0
Bathroom					
A-1........	58	1.2	3.0	1.0	5.2
A-2........	60	0.4	2.2	7.4	10.0
A-3........	35	.1	0.0	1.9	2.0
A-6........	42	1.2	.5	7.1	8.8
A-7........	35	0.5	3.0	3.0	6.5
A-8........	35	.8	3.0	3.0	6.8
A-9........	35	1.1	3.0	3.0	7.1
A-10.......	42	1.5	3.0	2.8	7.3
A-11.......	42	1.5	3.0	2.8	7.3
A-17.......	47	1.6	3.0	4.5	9.1
Average..	....	1.0	.....	3.7	7.0

Survey No.	Floor area	Combustible Contents			
		Movable property	Floor	Exposed woodwork other than floor	Total
Bedroom and bedroom closets combined					
	ft^2	lb/ft^2	lb/ft^2	lb/ft^2	lb/ft^2
A-1	110	3.7	3.0	3.1	9.8
A-1	136	5.4	3.0	4.6	13.0
A-2[a]......	86	3.9	3.0	1.9	8.8
A-3	188	4.1	3.0	2.3	9.4
A-6	133	7.3	3.0	2.5	12.8
A-7	128	6.5	3.0	2.2	11.7
A-7	145	6.7	3.0	2.0	11.7
A-8[b]......	133	5.0	3.0	3.2	11.2
A-9	138	6.2	3.0	4.0	13.2
A-10......	112	4.8	3.0	2.6	10.4
A-10[b].....	161	3.8	3.0	3.1	9.9
A-11	112	6.6	3.0	2.6	12.2
A-11[b].....	161	4.3	3.0	2.2	9.5
A-12	154	3.8	0.0	3.0	6.8
A-13[a].....	144	4.4	3.0	1.6	9.0
A-13[a].....	80	7.2	3.0	1.5	11.7
A-17	126	4.2	3.0	1.8	9.0
A-17	126	2.5	3.0	1.8	7.3
Average.	......	5.0	......	2.6	10.4
Dining room					
A-2	132	2.9	3.0	1.9	7.8
A-4	137.5	3.6	3.0	0.7	7.3
A-12......	224	3.0	0.0	3.5	6.5
Average.	......	3.2	....	2.0	7.2

[a] No closets.

[b] Two closets.

Note: 1 lb/ft^2 = 4.88 kg/m^2

Table 1. Summary Data for Apartments and Residences, Continued (Ingberg's Survey) [3]

Survey No.	Floor area	Combustible Contents: Movable property	Combustible Contents: Floor	Combustible Contents: Exposed woodwork other than floor	Combustible Contents: Total
Hallway					
	ft²	lb/ft²	lb/ft²	lb/ft²	lb/ft²
A-1	21	2.6	3.0	6.5	12.1
A-1	11	1.0	3.0	9.7	13.7
A-2	86	2.1	3.0	2.4	7.5
A-3	25	1.0	3.0	7.4	11.4
A-4	81	5.4	3.0	0.6	9.0
A-6	52	0.0	3.0	6.8	9.8
A-7	67	.0	3.0	5.8	8.8
A-8	42	.0	3.0	8.1	11.1
A-9	28	.0	3.0	5.5	8.5
A-10......	27	.0	3.0	7.7	10.7
A-11......	27	.0	3.0	7.7	10.7
A-17......	20	.0	3.0	9.5	12.5
Average.	......	1.0	......	6.5	10.5
Kitchen					
A-1	109	1.6	3.0	6.1	10.7
A-2	152	0.7	3.0	2.4	6.1
A-3	47.5	.2	0.5	4.0	4.7
A-4	148.5	.7	3.0	4.2	7.9
A-6	96	1.0	3.0	2.6	6.6
A-7	90	2.1	3.0	3.2	8.3
A-9	137	0.5	3.0	3.0	6.5
A-10......	171	.5	1.0	1.4	2.9
A-11......	171	1.8	1.0	1.7	4.5
A-13......	103	3.8	3.0	1.4	8.2
A-17......	87	0.7	3.0	4.5	8.2
Average.	......	1.2	......	3.1	6.8
Library					
A-12......	146	10.6	......	2.4	13.0

Survey No.	Floor area	Combustible Contents: Movable property	Combustible Contents: Floor	Combustible Contents: Exposed woodwork other than floor	Combustible Contents: Total
Living room					
	ft²	lb/ft²	lb/ft²	lb/ft²	lb/ft²
A-1	250	3.3	3.0	1.9	8.2
A-2	132	4.8	3.0	2.6	10.4
A-3	233	3.3	3.0	2.0	8.3
A-4	237.5	4.3	3.0	1.3	8.6
A-6	175	3.5	3.0	0.6	7.1
A-7	167	3.0	3.0	.7	6.7
A-8	213	3.6	3.0	1.9	8.5
A-9	167	4.6	3.0	1.1	8.7
A-10......	217	6.8	0.0	3.5	10.3
A-11......	217	1.4	.9	3.4	5.7
A-12......	224	4.4	.0	2.1	6.5
A-13......	202.5	4.3	3.0	1.6	8.9
A-17......	283	3.9	3.0	0.9	7.5
Average	....	3.9	......	1.8	8.1
Storeroom (apartment house)					
A-5	264	6.2	0.0	0.0	6.2
A-5	301	2.4	.0	.0	2.4
A-14.....	432	8.8	.0	.2	9.0
A-15.....	1,221	8.0	.0	.0	8.0
A-16.....	1,446	10.0	.0	.0	10.0
A-17.....	98	2.8	3.0	1.3	7.6
Average	....	6.4	......	0.3	7.2
Vestibule					
A-2	22.5	2.2	3.0	4.4	9.6

Ingberg's survey may be criticized on the statistical grounds that the sample size was too small, that there was no weighting of the data in terms of statistical significance or variation, and the data were not presented in a form that lent themselves to further analysis.

4. RECENT LOAD SURVEYS

The most recent residential loads survey for which reports were available are those of Karman [10,11] (Hungary), Sentler [12] (Sweden), and Williams and Dannenfeldt [13] (South Africa).

Sentler and Karman both estimated the maximum live loads to be expected in an apartment by assuming a number of changes (rearrangements of furnishings or changes in tenancy) during the life of the structure. Though Williams and Dannenfeldt considered fire loads, they had only a small sample of 6 houses and 2 apartments. This small a sample should be used only for getting a feel for the magnitude of fire and live loads and for estimating the approximate size of the sample for a comprehensive load survey.

4.1 Karman's Survey

Karman's [10,11] survey which was carried out in Hungary in the early 1960's appears to be the first residential load survey in which a serious effort was made to analyze the data from a statistical viewpoint.

The data were summarized into histograms, and the statistics of extremes was used to estimate the effects of changes of loads due to changes of tenants or rearrangements of furniture during the life of the residential unit.

Karman [10,11] surveyed 183 apartments distributed in Budapest, in suburban Budapest, in a provincial city and in a small village. The "apartments" included 88 single family-houses and 95 apartments in apartment buildings. His objective was to determine design loads for specification purposes.

The actual loads per room were analyzed under three different criteria: equivalent average room load, equivalent load for average moment, and equivalent load for average shear. He found that there was only a slight difference between these three methods, and so he recommended the use of the average room load as it is the easiest to use. It should be noted that this procedure may be inadequate and may be criticized on probabilistic grounds [4]. A better procedure would be to use influence surfaces for moment and shear [14], but this requires a very detailed analysis.

Karman attempted to describe distributions based on an estimated number of changes of occupants during the life of the structure. Though his analysis was based on the statistics of extremes, it was limited because he did not attempt to fit a probability distribution function to his data, which would aid in estimating the mean and the distribution of the tail, that is of the maximum loads.

Karman proposed a load reduction formula for large room sizes, but this does not seem to be justified. Note that Sentler [12] found no correlation of floor load and room size. The data from Karman's survey are summarized in table 2.

Table 2. Summary of Karman's Survey Furnishing Loads [10,11]

Room Type	Number of Rooms	Average Load	
		Kp/m^2	psf
Anteroom	155	21.8	4.5
Kitchen	175	36.3	7.4
Rooms*	500	38.6	7.9
Apartment**	183	36.5	7.5
Largest***	183	84.2	17.2

* not otherwise identified

** whole apartment

*** all the movable furnishings in the largest room in each apartment

Note: $1\ Kp/m^2 = 1\ kg/m^2$

$1\ psf = 4.882\ Kp/m^2$

Karman notes that design loads should include the effects of long term loading, of varying loads, and of short term heavy loads. He also uses the terms "static and dynamic fatigue" [10] to include all these effects.

4.2 Sentler's Survey

Sentler [12] applied an analysis, similar to that of Karman, using the theory of statistics of extremes. The survey included 120 apartment units which were located inside Stockholm and in the neighboring suburbs.

The material on which Sentler's [12] paper is based was originally gathered as part of a fire load survey for the Swedish Institute of National Defense which was reported by Sjolin in 1969 [15]. Nilsson [16] also analyzed this survey data, but his summaries were presented in a form that are unsuitable for comparison with other analyses. A summary of the results of this survey is given in table 3.

Table 3. Summary of Sentler's Survey [12]

	Number Observed	Mean (N/m^2)	Std. Dev. (N/m^2)	Mean (psf)	Std. Dev. (psf)
Prior to 1940					
Sitting Rooms	65	317.9	124.2	6.6	2.6
Bedrooms	73	264.0	112.2	5.5	2.3
Hallways	14	201.7	88.2	4.2	1.8
All Rooms	152	289	121	6.0	2.5
Post 1940					
Sitting Rooms	67	265.8	95.7	5.6	2.0
Bedrooms	89	198.4	79.4	4.1	1.7
Hallways	33	86.1	88.5	1.8	1.8
All Rooms	189	227	93	4.7	1.9

1 psf = 47.880 N/m^2

Sentler notes that his results are lower than Karman's [10]. He attributes this to differences in life styles in Hungary and Sweden. He also concludes:

1. The live load for sitting rooms and bedrooms is independent of size.

2. There is no justification for reducing the allowable live load for larger rooms.

3. In terms of numbers of rooms in each dwelling unit, apartments with a greater number of rooms tend to have a lower maximum live load than those with fewer rooms.

4. Design loads should include the effect of short term heavy loads[4].

Sentler fitted two different continuous probability distribution functions to his data; following this he estimated the expected effect on the live load of subsequent changes of tenants by using the statistics of extremes [17,18,19]. Sentler suggested that if a more conservative, i.e., a higher upper bound, estimate is desired the log-normal distribution should be fitted to the data, otherwise he suggested that the gamma distribution be used because it appears to fit the original data better [20]. He feels that both these distributions provide a good fit to residential load survey data.

4.2.1 Method for Estimating Effect of Load Changes

The theory behind Sentler's method has been published elsewhere [17,18,19]. The procedure is to first plot the survey data as a histogram. Next fit a suitable probability distribution function (pdf) to the data. Sentler used both log-normal and gamma distributions. The gamma distribution is to be preferred because the upper tail has an exponential form, and there are indications that it fits load survey data better than the log-normal distribution [20].

From the selected pdf calculate the cumulative probability function (cpf). The pdf, after a number of changes of occupancy of the maximum of the n changes, is given by:

$$f_n(x) = n \cdot [F_x(x)]^{n-1} \cdot f_x(x) \quad \underline{5/}$$

where $f_n(x)$ = pdf after n changes evaluated at a load x

n = number of changes of occupants (loading) in life of structure

$F_x(x)$ = cpf from survey data evaluated at a load x

$f_x(x)$ = pdf from survey data evaluated at a load x

If we substitute on the right-hand side of the equation the probability values for the maximum expected load, or the maximum load that may occur with a probability of P (which may be some value like 95%, 99.9% etc.), we will get the probability of the occurrence of the maximum load due to a specified number of changes of occupants or loadings during the life structure. Table 4 shows that the value of the largest average load after only five changes increases to over 150% of the original value.

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[4] These might be produced by large gatherings of people and during renovation when the furniture from several rooms might be placed in one room.

[5] Detailed derivation of this equation are given in references [10] and [12].

Table 4. Expected Changes in Largest Average Load after Changes in Occupants - Sentler's [12] Survey, Built after 1940

Type of Distribution	No. of Occupant Changes	Mean		Ratio to Original Data
		(N/m^2)	(psf)	
Original Value	1	227	4.7	1
Log-normal Distribution	5	358	7.5	1.58
	10	416	8.7	1.83
	15	451	9.4	1.99
Gamma Distribution	5	343	7.2	1.51
	10	398	8.1	1.72
	15	415	8.7	1.83

Note: 1 psf = 47.880 N/m^2

4.3 Williams and Dannenfeldt's Survey

Williams and Dannenfeldt [13] carried out a survey of six dwellings and two flats (apartments), in the Union of South Africa in 1974. The objective was to develop criteria for the fire resistance required for fire barriers in residential occupancies.

Initially a catalog of furnishings was assembled for use by the surveyors. The catalog entries had previously been analyzed for weight, size, and materials. The householder was to identify the furnishings by the appropriate catalog entry. This turned out to be impractical because of the normal changes in furniture styles and the large variety of furniture types. The procedure was then changed to having surveyors weigh all the furnishing items and identify them with the closest furnishing item in the catalog.

The observed fire loads (see table 5), were within the range reported in BMS 92 [3]; however, the authors' assumption that these surveys are representative of the fire loads in all residences in the Union of South Africa is questionable. This will be discussed below.

Table 5. Williams and Dannenfeldt's Survey - Contents Fire Load [13]

Unit No.	FIRE LOAD kg/m² * psf									
	Bedrooms				Lounge		Dining Room	Entrance Hall Passage	Study/ Sewing Room	Kitchen
	1	2	3	4	1	2				
Houses										
A	21.4 4.4	14.1 2.9	-	-	11.2 2.3	-	-	9.2 1.9	-	8.7 1.8
B	20.4 4.2	12.1 2.5	19.0 3.9	21.4 4.4	8.7 1.8	-	10.2 2.1	**	17.5 3.6	10.7 2.2
C	21.4 4.4	18.0 3.7	20.4 4.2	28.2 5.8	9.7 2.0	18.5 3.8	21.4 4.4	**	-	5.3 1.1
D	21.4 4.4	29.6 6.1	32.6 6.7	-	11.7 2.4	-	11.7 2.4	**	23.8 4.9	18.9 3.9
E	12.6 2.6	9.7 2.0	14.6 3.0	-	6.8 1.4	-	14.1 2.9	**	-	5.8 1.2
F	29.6 6.1	22.8 4.7	24.3 5.0	-	6.3 1.3	-	39.8 8.2	15.6 3.2	-	13.6 2.8
Flats										
A	16.5 3.4	11.7 2.4			-	-	6.8*** 1.4	14.6 3.0	-	15.6 3.2
B	24.3 5.0	31.6 6.5			-	-	12.6*** 2.6	-	-	38.8 8.0

* 1 psf = 4.882 kg/m²

** Negligible

*** Room actually described as "lounge/dining room"

5. METHODS FOR ESTIMATING SAMPLE SIZE

There are a number of methods for estimating the sample size required for a survey. The method or methods that may be used will depend on (1) the nature of the data, that is, how much information we have *a priori* about the population that we are sampling; (2) the statistic that we wish to control, such as mean or standard deviation; and (3) the level of accuracy that is acceptable. Most of the methods are sensitive to the level of accuracy; that is, for a higher level of precision or certainty a larger sample size is required. Some methods are relatively independent of population size provided the population exceeds a "small population" size [21]. These will not be discussed here as they do not appear to be appropriate for a loads survey. Two methods of estimating sample size will be described. These methods of sample size determination are for simple random samples. Because of the difficulties in conducting a load survey, advanced survey design methods do not appear justified at this time even though they could lead to smaller sample sizes. The first is based on the sample mean; the second is based on the sample standard deviation. Both are from Natrella's Handbook [22].

5.1 Method 1 - Size of Sample Based on Sample Mean

This method uses either Student's t distribution or the normal distribution. Student's t distribution is used if we have an estimate of the population standard deviation based on a known sample size. The normal distribution is used if we know the population standard deviation or we can assume some value for it.

We wish to know the sample size required to estimate the mean m of a population. We are willing to take a risk that our estimate is off by d or more. There is available an estimate s of the population standard deviation σ based on q degrees of freedom, where q is usually one less than the sample size.

1. Choose d, the allowable margin of error, and α, the risk that our estimate of m will be off by d or more.

2. Look up $t_{1-\alpha/2}$ for q degrees of freedom in a table of Student's t distribution.

3. Compute

$$n = \frac{t^2 \ s^2}{d^2}$$

where n = the sample size required

t = value of $t_{1-\alpha/2}$ for q degrees of freedom

s = estimate of population standard deviation

d = permissible error in estimate of the mean

α = level of risk that an error has made i.e., probability that the population mean will lie outside the interval $m \pm d$

The method will be illustrated with examples.

5.1.1 Examples of Sample Size Estimates, Method 1

The data from Ingberg's [3] survey and from Williams and Dannenfeldt's survey [13] will be used to estimate the required survey sample size using Method 1.

5.1.2 Ingberg's Data

Ingberg's data, which is shown in table 1, will be used to estimate the sample size required. The calculations in each case are made using unweighted data.

Case 1 uses the data from the entire apartment.

Sample mean = 3.4 psf

sample standard deviation = 0.76 psf

estimate of population standard deviation = 0.73 psf

α = 0.05 (95% certain that we will not be in error)

$T_{1-\alpha/2}$ = 2.179 with 12 degrees of freedom

$$n = \frac{t^2 s^2}{d^2}$$

where n = sample size required

d = permissible error in the estimate of the mean

s = estimate of population's standard deviation

Let d = 5%, 10%, 20% of the sample mean; the results of the analysis are shown in table 6.

Table 6. Estimate of Sample Size Based on Entire Apartment-Ingberg's Data [3]

d % of Mean	d psf	n No. of Apts
5	0.17	88
10	0.34	22
20	0.68	6

Another way of using the data to estimate the number of dwelling units would be to look at the individual room data.

For 75 rooms we have the following data:

Average number of rooms per apartment = 5.77 rooms/apt

sample mean = 3.17 psf

sample standard deviation = 2.54 psf

estimate of population standard deviation = 2.52 psf

t = 1.990 for 74 degrees of freedom

let d = 5%, 10%, 20% of the sample mean, the results of the analysis are shown in table 7.

Table 7. Estimated Sample Size Based on Individual Ingberg's Data [3]

d % of Mean	d psf	n No. of rooms	Equiv. No. of apts.
5	0.16	982	171
10	0.32	246	43
20	0.63	64	11

In both cases the required sample size goes up sharply with the desired accuracy. The difference between the sample size produced by the two sets of calculations is that the entire apartment load represent an average or smoothing of the data; that is, it shows less variability than the individual room data. Weighting the data according to room size indicates additional variability in the data and so shows larger required sample sizes.

5.1.3 Williams and Dannenfeldt's Data

The data of Williams and Dannenfeldt will be tested using the individual residence room contents.

number of residences	=	6
number of rooms	=	45
average number of rooms per residence	=	7.5
sample mean	=	15.4 kg/m^2
sample standard deviation	=	9.0 kg/m^2
estimate of population standard deviation	=	8.9 kg/m^2

let d = 5%, 10%, 20% of the sample mean

α = 0.05

t = 2.571 for 5 degrees of freedom

The results of this analysis are shown in table 8.

Table 8. Estimated Sample Size Based on Residence Data Williams & Dannenfeldt Data [13]

d % of Mean	d kg/m^2	n No. of rooms	Equivalent No. of Residences
5	0.77	884	118
10	1.54	221	30
20	3.08	55	8

As before the data were unweighted.

5.2 Method 2 - Size of Sample Based on Precision of the Standard Deviation

We may wish to know the size of sample required to estimate the standard deviation with a certain precision. If we can express this precision as a percentage of the true (unknown) standard deviation, we can use the curves in figure 1.

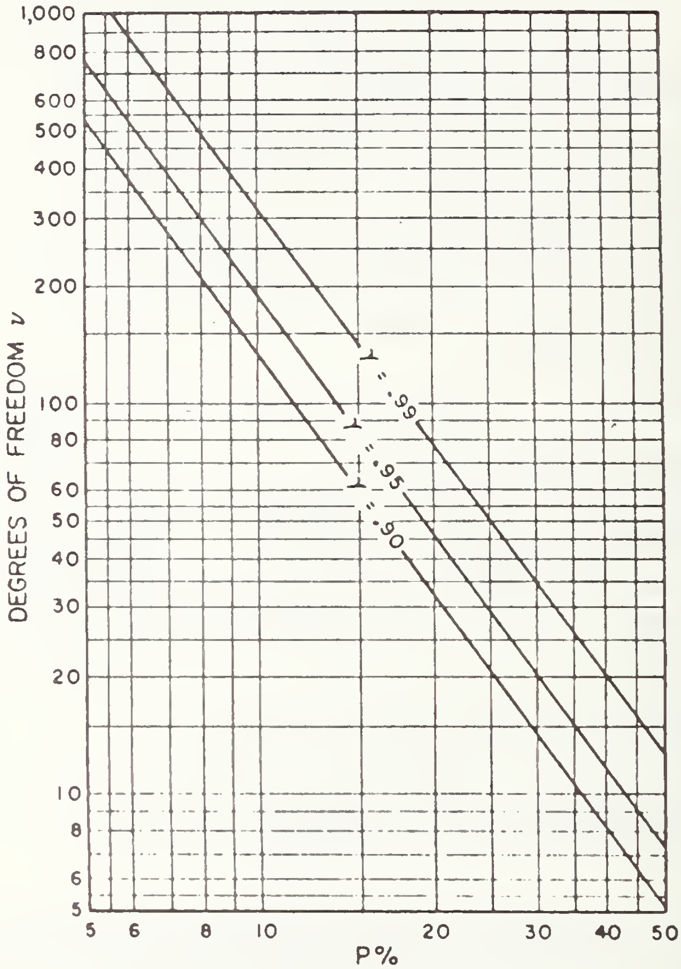

Figure 1. Number of degrees of freedom required to estimate the standard deviation within P% of its true value with confidence coefficient γ. [22][6]

[6] This figure is reproduced thru courtesy of the Journal of the American Statistical Association, Vol. 45 (1950), p. 258 from an article entitled "Sample Size Required for Estimating the Standard Deviation as a Percent of its True Value" by J. A. Greenwood and M. M. Sandomire. It also appeared in "Experimental Statistics" by Mary G. Natrella [22].

5.2.1 Example of Sample Size Estimates, Method 2

For example, let us say that we wish to know how many samples we should have in order to estimate the standard deviation within 10% of its true value with a confidence of .95. Referring to figure 1 and going vertically from P = 10% to the curve $\gamma = 0.95$, we find that the degrees of freedom, that is the sample size minus one, is approximately 190.

5.3 Limitations on Sample Size Selection Methods

The limitations on this and other methods of selecting sample size are that they assume that the data is from the same population, or the same strata of the population. Among residences additional variables are number of rooms per unit, size of unit, value of unit, room type, socio-economic class of resident, geographical region, etc.

A priori we may have little or no information on the effect of these and other variables on loading. One way of proceeding would be to select an initial survey size. The actual sample or the results should be stratified, with the stratifications being based on factors relating to the differences between units. The strata should then be examined for differences and based on the sample mean and standard deviation a new sample size is determined with the desired level of confidence. If the new calculated sample size is less than the number surveyed in each strata, then no further sampling is necessary. If the new calculated sample size is more than the number surveyed in any strata, it is necessary to survey only enough additional units to make up the required totals.

6. SURVEY GUIDES

6.1 Literature Guides

In addition to residential load surveys and statistical methods, the following three sources of general information on the conduct and evaluation of surveys were felt to be of value to the manager and project leader concerned with surveys.

"The Household Survey Manual - 1969" [23] outlines Federal Government policy on household surveys and describes some of the difficulties of carrying out surveys. This manual is oriented towards sociological or demographic types of surveys. It contains useful information on the design of questions and questionnaires, which may be helpful when planning other kinds of surveys.

"An Introduction to Sample Surveys for Government Managers" [24] complements the "Household Survey Manual." It is oriented towards the nitty gritty of the objectives, conduct and costs of surveys. It is very concise and reads easily.

"Evaluation Research" [25] discusses methods of assessing program effectiveness and survey effectiveness. Both references [24] and [25] are non-mathematical and are written for non-statisticians.

These last three references suggest that surveys are frequently difficult and expensive to carry out. The survey should be designed and pretested on small samples before embarking on a full size survey. The planning, conduct methodology, and pretesting of the survey should be completed before beginning the larger survey.

6.2 Survey Costs

The cost of the actual field survey is small compared to that of the planning, computer programming, logistics and supervision.

The following list of eleven cost elements is from Weiss and Hatry [24].

Cost Elements in Sample Surveys by Function

1. Overall survey planning, design, and direction.
2. Listing the units (blocks, households, individuals, businesses) to be sampled.
3. Selecting the sample, preparing maps, instructions, and assignment schedules.
4. Developing the interview questionnaire and schedule (including pretest costs for interviewing and travel).
5. Printing questionnaires, training materials, instruction manuals.
6. Interviewing.

    a. Recruiting and selecting interviewers.

    b. Interviewer training (trainer, training materials, plus interviewer time).

c. Contacting and interviewing, calling back, locating missing respondents.

d. Field supervision.

e. Travel (time and expenses).

7. Editing, coding, keypunching, tabulating, computing, and if used, computer time.

8. Telephoning, especially if a survey is by telephone or if interviews are validated by telephone.

9. Mailing, particularly if a survey is by mail, or when explanations, introductions, and appointments are made by mail.

10. Analyzing data and report writing.

11. Reproducing the report.

7. SUMMARY

During the course of the literature search only four residential load surveys were uncovered for which reports were available and for which the data was presented in a form suitable for comparison. These were by Ingberg [3], Karman [10,11], Sentler [12], and Williams and Dannenfeldt [13]. The first and fourth were concerned with fire loads, while the other two were concerned with live loads. Ingberg [3] used a sample of 13 residential units; Karman used a sample of 183 units; Sentler used 341 units. Williams and Dannenfeldt's survey used too small a sample and their results were inadequately summarized from a statistical viewpoint. Karman and Sentler extensively analyzed their data and used the statistics of extremes to estimate the maximum expected loads.

A common error in load surveys is to assume that the maximum observed load is the maximum expected load and is suitable as a design load [1]. The maximum expected load can be estimated using the methods of statistics of extremes. Both Karman [10,11] and Sentler [12] state that the effects of dynamic loads, long term loads and short term heavy loads should be included in any code or design specification. Similar considerations apply to the effects of fire loads.

Since household furnishings are almost completely combustible, in the absence of other information, it may be possible to estimate the fire load from the total live load in a residence. The room finish material may also add significantly to the total fire load [2].

Field surveys are generally difficult and expensive [23,24,25]. The costs of surveys can be reduced by limiting the scope of the survey, by establishing clear objectives, by understanding the limitations of surveys, and by small scale pretesting of the survey procedures. The cost of the field survey is only a small part of the total expenditure. Most of the expenses arise in the work that must be done prior to the field survey such as planning, design and printing of forms, recruiting, computer programming, etc., and in the work that is done after the survey such as keypunching and analyzing the data, and report preparation and printing.

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15. SUPPLEMENTARY NOTES

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.)*

A search of the literature shows that most load surveys have been concerned with commercial and industrial occupancies and only a few have dealt with residences. Many surveys have been inadequately reported from a statistical viewpoint, and the data have been misapplied. A common error has been to assume that the largest observed load is the largest expected load. The statistics of extremes should be used to determine reasonable design values. Methods for estimating the sampling size (for a prescribed accuracy) are given and illustrated with examples.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*
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