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HORIZONTAL AND VERTICAL CIRCULATION IN UNIVERSITY INSTRUCTIONAL AND RESEARCH BUILDINGS.

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TO FACILITATE CIRCULATION PLANNING IN BUILDINGS USED FOR HIGHER EDUCATIONAL INSTRUCTION AND RESEARCH, A PILOT STUDY WAS CONDUCTED WITH THE INTENT OF DEVELOPING GENERALIZED RECOMMENDATIONS FOR HORIZONTAL AND VERTICAL CIRCULATION FACILITIES. A SURVEY TECHNIQUE WAS DEVELOPED AND APPLIED TO FOUR CLASSROOM AND TWO RESEARCH BUILDINGS IN ORDER TO OBSERVE AND RECORD--(1) CIRCULATION ON PARTICULAR FLOORS DURING PEAK WORK LOADS, (2) NUMBER OF PERSONS IN EACH ROOM ON A FLOOR DURING THE MORNING, (3) THE LENGTH OF THE KEY CIRCULATION ROUTES, (4) TRAVEL TIME OF KEY ROUTES DURING NON-PEAK PERIODS, AND (5) TRAVEL TIME OF KEY ROUTES DURING PEAK PERIODS. DATA ON PERMISSIBLE DENSITY, CLASSROOM UTILIZATION AND PLANNING STANDARDS WERE CONSIDERED IN THE RECOMMENDATIONS FOR HORIZONTAL CIRCULATION. IN ADDITION TO THESE FACTORS, VERTICAL CIRCULATION RECOMMENDATIONS CONSIDERED LAND, BUILDING AND CIRCULATION FACILITIES COSTS. IN ORDER TO PLACE THE STUDY WITHIN THE FRAMEWORK OF CORRECT DESIGN PRACTICE THE HORIZONTAL AND VERTICAL CIRCULATION RECOMMENDATIONS WERE COMPARED WITH BUILDING CODES OF TWO CITIES, THREE STATES AND TWO NATIONAL ASSOCIATIONS. IN ADDITION TO INTRA-BUILDING CIRCULATION, CLASS SCHEDULING AND PHYSICAL PLANT LOCATION WILL DETERMINE CIRCULATION TIME AND DISTANCE. SURVEY PROCEDURE AND THE DATA COLLECTION FORM ARE PRESENTED IN THE APPENDIX. (BH)

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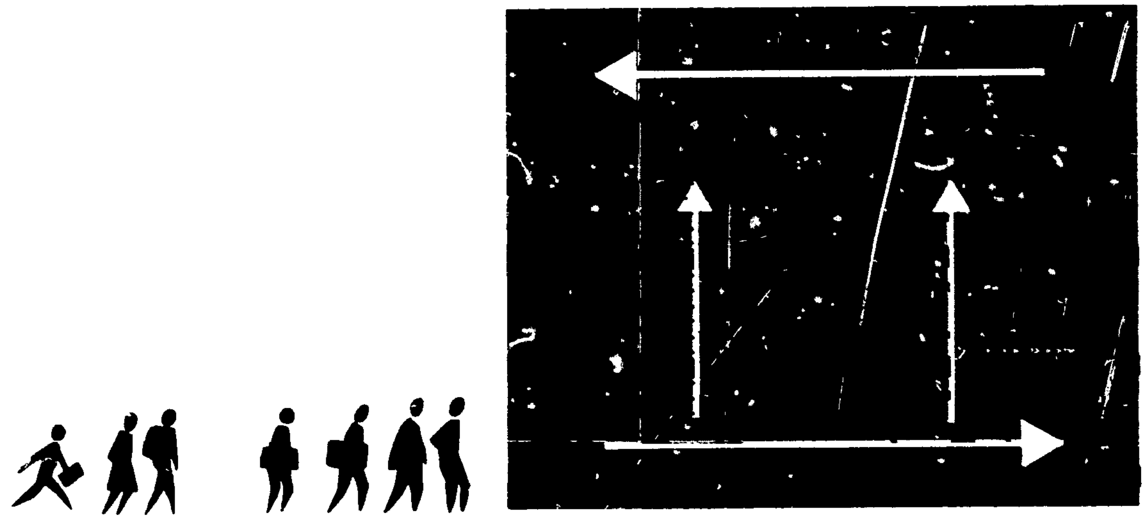

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The Background

Unprecedented enrollment increases in American colleges and universities are with us and ahead of us. These same institutions are greatly expanding their activities in the fields of research and service to the public. All of this adds up to the creation of a need for new building facilities in a magnitude never before experienced.

The University Facilities Research Center has recently completed a building survey while studying immediate needs for instructional, research, operating and housing construction at the large middlewestern universities comprising the Council of Ten and the University of Chicago. This survey covered the period from the end of World War II through the ten year forward planning time adopted by the eleven universities. It indicated that approximately $1.85 billions in construction could be expected between 1946 and 1970. Of this about $1.1 billion in construction, or 60%, is now being planned or built or projected for the near future. On a national scale, this would indicate college and university building programs amounting to something in the order of $15 billion between now and the end of this decade.

Among the objectives of the Research Center is the isolation of planning and design criteria problems, followed by the finding or developing of measures for design—all to the end of permitting the best possible use of the university and college construction dollar. Analysis of statistics and interviews and conferences with interested people in the field have contributed to the selection of several monograph subjects, of which this publication is one.

The material is aimed at aiding university and college administrators and their planning and building committee people. It is also directed at private architect and engineer firms engaged in the design and execution of new facilities.

Circulation in University Instructional and Research Buildings was selected as a subject for study for several reasons. Colleges and universities generally, and especially the larger ones, have found that their growing enrollments have led to greatly increased densities of land use for the central campus. Land values have risen steadily, and will continue to do so. All of this has directed university administrators' and planners' attention to the high rise building as a logical solution for the future.

The high rise building, or the large walk-up building for a university presents several unique conditions that must be understood if successful and economical structures are to be built. The distance between buildings, the time required to move within them, the time allowed between classes, the appropriateness of elevators or escalators—all are design criteria items that require definition. What is the "break point" for building heights and vertical transportation provisions?

Building codes usually do not recognize college and university facilities as a building type different from primary and secondary educational units. Are the "two-way peaks" usual in the movement of people in university buildings realistically covered in code exit regulations which have been written mainly to provide evacuation provisions for somewhat different circumstances?

To find the answers to these questions, and to put the findings into a form of value in pursuing the planning and designing of future college and university buildings, the Research Center engaged the services of Taylor, Lieberfeld and Heldman, Inc. of New York, Consultants in Space Utilization, Building Programs, Management Controls. This organization has had considerable recent experience in the college and university field; it was selected because of this background.

The body of this monograph, its findings and its recommendations are very largely the work of the Consultants.

WS Kinne Jr.

Madison, Wisconsin, November, 1961

Director, University Facilities Research Center

I. *The Case*

Corridors and stairs account for approximately 20 percent of the gross area of college buildings.[1] In buildings with elevators or escalators the percentage of area devoted to circulation is even higher, and the equipment itself is an important element in total cost. There is general agreement that circulation facilities should be held to the minimum consistent with proper functioning, but very little agreement on what this minimum is.

In fact circulation has long comprised a sort of no man's land in the planning process. The first phase of planning is usually the development of a program, to a large extent the responsibility of the client. The elements of the program are independent of the form of the building, so that the client can measure both the number and size of requirements such as offices, laboratories and other areas expressing his activities. Circulation cannot be quantified at the programming stage because it is dependent on the height, extent and shape of the building.

Therefore, circulation is defined by the architect in the course of the second phase of planning, the actual designing of the building. In buildings for higher education this may raise some problems. First, there is an informational vacuum in the relationship between the particular activities occuring in college buildings and the area required to provide for their circulation. Second, there are complex and heterogeneous bodies of regulations which impose mandatory specifications for circulation but rarely recognize the nature of college campus activities. These are the building codes, varying from state to state, oriented towards primary and secondary school operations, and concerned more with the evacuation of buildings than with their overall functioning.

The purpose of this monograph is, first, to suggest a functional basis for planning circulation in buildings for higher education, without reference to codes. Then, in order to place the study within the framework of current design practice, a comparison of the Consultant's recommendations with code stipulations is included.

It is worth stressing that, though specific recommendations are offered, the present work is more in the nature of a pilot study than a definitive treatise. The surveys conducted in the field, though representative, are not numerous enough to be convincing through their purely statistical weight. They have served to a considerable extent to confirm impressions based on the experience both of the Consultants and of a number of college administrators with whom the Consultants have discussed this subject.

The study is concerned with buildings for instruction and research. However, for estimating circulation requirements it is more useful to consider buildings with these functions as serving either a predominantly transient population, as does a classroom building, or a predominantly stable population, as does a research or faculty office building. The first category produces the most intense work loads on circulation facilities. These building types are, of course, almost never found in pure form. Classroom buildings may include office space, for example, but the presence of offices, while reducing the overall density of population in the building, will not affect the general approach to the design of corridors and stairs.

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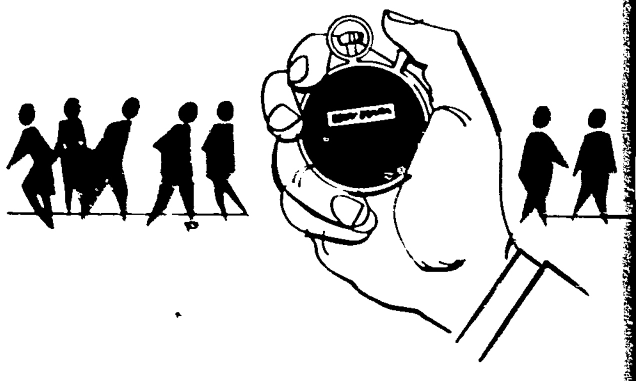
[1] This figure of 20 percent is based on an analysis of twelve major post-World War II university buildings. Corridors amount to over 16 percent and stairs to over 3 percent of the gross area of the buildings.

II. *Survey Theory and Technique*

In order to formulate generalizations concerning circulation it is necessary to observe the operation of corridors, stairs and elevators in a number of representative buildings under varying work loads. These observations must then be evaluated. This implies defining the characteristics of adequacy in reference to means of circulation. When is a corridor too crowded? When are the occupants frustrated in reaching their objectives because of inadequate stair or elevator facilities? How can design factors be isolated? And finally, what is the optimum relationship of building population to circulation areas?

The answers to these questions can be found by considering the basic function of the circulation facilities and determining how well, in a specific building, this function is being fulfilled. Corridors. stairs and elevators exist in order to permit movement from point to point in the interior of a building and from any interior point to the outside. How effectively this is done may be considered as equating with the rate of travel permissible to the occupants. Thus if a representative individual is able to proceed from a classroom to a stair under apparently crowded conditions at the same rate as when walking alone, then one must conclude that crowded conditions in the corridor along which he travels do not impede his progress and that the corridor space provided is adequate. On the other hand, varying densities of persons per 1,000 square feet of corridor space may result in different rates of travel on the part of the occupants. In that case the adequacy of the corridor must be measured against the amount of time permitted for the fulfillment of the occupants' objectives at a particular time of day, e.g., proceeding to the next class. In addition the corridor must at all times be suitable for implementing evacuation in case of emergency.



With this approach in mind a field survey was designed comprising the following principal features:

1. Observation of particular floors in college and university buildings at peak work loads, that is, during the morning hours of those weeks when classes were in session.
2. Recording the number of persons present in each room on the floor at different hours from the first class through lunch period.
3. Measuring the length of key travel routes on each floor, e. g., from the room farthest from any stair to the stairway.
4. Recording the time required for an individual to traverse the key routes during a period when the corridors were not otherwise loaded.
5. Repeating the procedure in 4.) during periods when the corridors were most heavily loaded, i. e., in classroom buildings at the ten minute intervals between classes.

The observations and measurements were extended to include data on elevators and stairs as well as corridors. Vertical and horizontal travel distances and rates were recorded. The complete survey form and instruction sheet appears in the Appendix.

This type of survey potentially harbors the major disadvantage that the observer may not find what he is looking for. That is, if the objective is to discover the peak or maximum permissible density, it is quite possible that direct observation will not enable the survey personnel to identify such a point. However, such a point may be estimated if the data reveal any correlation between travel time and density. Then if the minimum acceptable travel rate can be established, the maximum permissible density (density is defined as population per thousand square feet) can be readily determined. This is illustrated by the following graphic model.

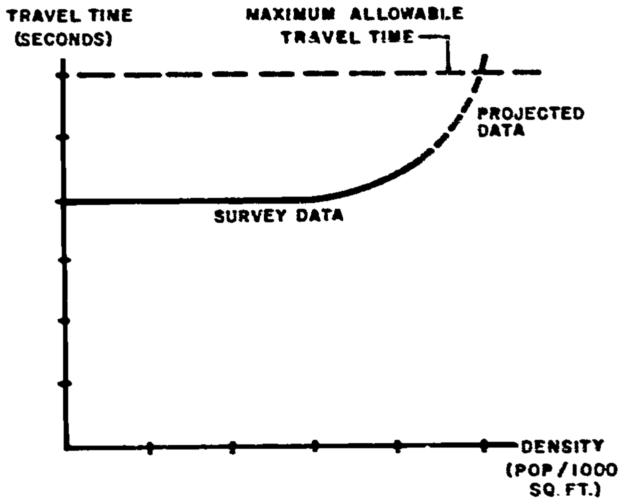


Figure 1. Diagram indicating the theoretical relationship of travel time to density in corridor circulation.

The normative data on rates of travel are compounded of the following elements:

1. Occupants' destination: This is the key point in college buildings. The critical situation for which one must design is that of the student (or instructor) who has ten minutes to leave a room in one building and arrive at a room in another building. Currently, as campuses grow in size and population, the distance between buildings is increasing. Some institutions have gone to the considerable expense of revising their building assignments to avoid extending the ten-minute class break.

What this implies for a study of circulation facilities is reinforcement of the goal that passage through a corridor and down a stair by a group at class break time should be at the same rate as is permitted to an individual travelling during the class session. If corridor and stair permit this rate of travel, then nothing more can be demanded of these facilities. Such a criterion can well supersede subjective estimates as to what constitutes overcrowding.

2. Normal pace: The limited literature and research on this topic indicates a speed for males of from four to four and one-half feet per second. However, most surveys upon which such information was based were made outdoors; there is some evidence that for psychological reasons walking speed indoors is somewhat lower.

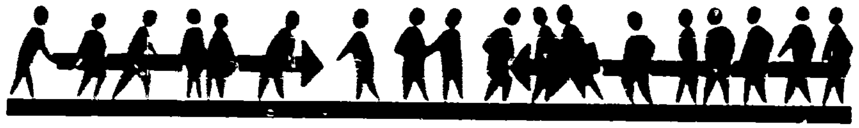
3. Fire safety: The Building Exits Code of the National Fire Protection Association is probably the most explicit in this regard; it assumes that all occupants can be evacuated from their rooms to a fire stair in 80 seconds, with the stair a maximum of 100 feet from the most remote room and with the corridor width varying with the number of occupants. Very probably, a case can be made for characterizing the fire safety provisions of most codes as over-stringent for university buildings because of the comparatively small

proportion of combustible contents (except in laboratories) and because of the very minute proportion of the aged and infirm, whose disabilities are built into the typical regulations for exit design, including corridors and stairs.

In order to ensure a reliable sample, the Consultants adopted the following criteria in selecting buildings to be included in the survey.

1. The building should be either of recent date or should conform to present-day construction practice.
2. The building should be simple and regular in shape, with clearly defined circulation patterns. In practice all but one of the buildings used were of elongated form with single corridors having rooms on both sides.
3. The building, or at least the floor or floors to be surveyed, should have a capacity of several hundred persons and sufficient range of intensity of use so that the effects of different densities might be observed.
4. The sample locations should be in structures which are part of a multi-building campus, so that the traffic to and from typical scheduled rooms is a composite of students proceeding from outside the building, from other floors within the building, and from other rooms on the sample floor.

The field surveys actually conducted by the Consultants took place in four buildings devoted principally to classrooms and in two other designed for research. The findings and conclusions based on the field work were checked against a dozen other buildings where plans were available and where, in a number of instances, the evaluations of architects and administrators were known.



III. Horizontal Circulation

A. Classroom Buildings—Permissible Density

In the preceding paragraphs it was posited that the survey data might vary with the density of persons per square foot of corridor. Although the conditions actually observed might not be identifiable as maxima or upper limits of permissible density, such limits could be projected (see Figure 1).

In practice this procedure was not feasible because the rates of travel were not depressed by the actual densities under observation. The corridors under observation were not sufficiently crowded to indicate a consistently changing relationship between density and travel time. Nevertheless, the fact that in all but one of the field survey situations the rate of travel during the class break was identical with that obtaining during the class session constitutes useful information. The densities noted were established as permissible, though admittedly even greater densities might be possible.

Table 1 shows the densities and corresponding travel times observed in four sample buildings. In examples A, B, and C the elapsed time from the most remote classroom door to the stair which serves the classroom is not greater during the class break than during the class session, when density is not a factor. In example D it took longer to proceed to the stair during the ten minute class break interval. However, it is felt

TABLE 1. Corridors: Rates of Travel from Most Remote Point[a] to Stair for Selected Floors of Four Classroom Buildings

Survey Location and Hour	Number of Persons per Floor	Corridor Density (population per 1000 square feet)	Travel Time from Most Remote Point[a] to Stairs: During Classes (in seconds)	Travel Time from Most Remote Point[a] to Stairs: Between Classes (in seconds)
Example A (capacity 330)				
9:00— 9:50	186		20	
9:50—10:00		98		18
10:00—10:50	227		20	
10:50—11:00		119		20
11:00—11:50	115		20	
11:50—12:00		60		20
12:00—12:50	194		20	
12:50— 1:00		102		20
Example B (capacity 601)				
9:10—10:00	124		21	
10:00—10:10		142		20
10:10—11:00	131		21	
11:00—11:10		151		21
11:10—12:00	92		21	
12:00—12:10		106		21
Example C (capacity 228)				
9:10—10:00	57		5	
10:00—10:10		59		5
10:10—11:00	45		5	
11:00—11:10		47		5
11:10—12:00	92		5	
12:00—12:10		96		5
12:10— 1:00	56		5	
1:00— 1:10		58		5
Example D (capacity 485)				
9:05— 9:55	175		20	
9:55—10:05		107		17
10:05—10:55	157		20	
10:55—11:05		96		17
11:05—11:55	207		20	
11:55—12:05		125		17
12:05—12:55	217		21	
12:55— 1:05		132		17

[a] The most remote point is defined as the classroom door at the greatest distance from a stairway.

that the presence of a four-car elevator bank on this floor (the eighth floor of the building) reduced the effective capacity of the corridor; there is reason to believe that, except for the crowding which took place at the elevators, the elapsed travel time at the class break would not have exceeded seventeen seconds. It is interesting to note that, in one instance (example B), the elapsed time at the class break, with a corridor density of 142, was one second less than the time required to traverse the same route when classes were in session. Actual speed in these examples varied from 3.4 to 4.2 feet per second, which is reasonably close to average walking rates.

Partly as a result of this data and partly on the basis of more general experience, a figure of 165 persons per 1,000 square feet of corridor is suggested as an acceptable upper limit. To the extent that the survey samples are typical, this figure automatically provides for the effects of two-way traffic, students chatting in the middle of the corridor and such other individually indeterminate elements.

B. Planning Standards and Classroom Utilization

If all the seats in a classroom building were filled at all hours of the teaching week, that is, if utilization were equal to capacity, then the suggested corridor density of 165 persons per 1,000 square feet would be useful as a planning standard in the design of the building. The architect would simply provide six square feet of corridor space for each classroom seat.

However, this would overstate the real circulation requirements, for in practice there are always more seats than there are students at any one hour. The problem, then, is to discover the ratio between utilization and capacity. Then the density figure of 165 can be increased to take advantage of this difference between full capacity and average, or even peak use.

To do this involves the introduction of three measures of utilization:

1. Room utilization refers to the percentage of available classrooms in use at a particular hour of the day or throughout the teaching week.
2. Student station utilization refers to the percentage of seats filled at the hours the classrooms are scheduled.
3. Capacity utilization refers to the product of the percentages of room and student station utilization.

Various studies made in the past five years indicate that room utilization averages only about 50 percent of a 44-hour week. Student station utilization is not much higher and the product of the two probably averages around 30 percent. However, there is evidence that these figures are rising and that effective pressures for more intensive use of space are currently operative. An average of 80 percent room utilization and 70 percent station utilization would represent a goal desired by many but achieved by only a very few institutions today.

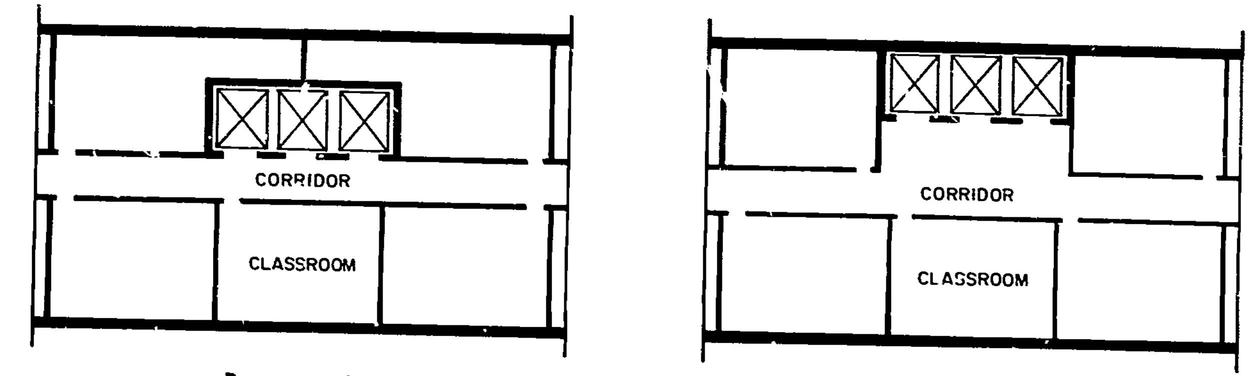
Nevertheless, if a weekly average is used as a basis for planning circulation facilities, corridors may prove inadequate at the peak hours or sequences, e.g., Monday, Wednesday, Friday at 10 A.M. in some institutions. At such times room utilization of 90 percent and student station utilization of near 75 percent might be obtained. Any utilization factors higher than these would probably occur only very rarely and in only a very few institutions, perhaps in a few with "block" scheduling.

In consequence what is presented as a planning standard valid for the future as well as the present is a capacity utilization rounded to two-thirds of the available stations, based on the product of 90 percent room utilization and 75 percent (actually 74.1%) station utilization.

If this figure is then applied to the previously derived maximum permissible density of 165 persons per 1,000 square feet of corridor space, the result is 165 ÷ 2/3 = 247.5, which may be rounded to 250 persons.

Thus, in planning classroom buildings the recommended procedure would be to provide 1,000 square feet of corridor for every 250 seats in the classrooms, or 4.0 square feet of corridor per station.

Two corollary points should be noted in reference to permissible densities. It is desirable for traffic to flow into the corridor as evenly as possible. Two classroom doors directly opposite each other tend to create a bottleneck. In most cases it should be possible to stagger the doors. Another bottleneck can be created by the presence of elevators, if those persons waiting for the elevator serve to block the passage of others proceeding along the corridor. Therefore space should be provided adjacent to the elevator bank but separate from the main corridor. Such space should be approximately equal to the sum of the areas of the elevator cabs.



Poor practice

Good practice

Figure 2. Corridor Details

C. Other building types

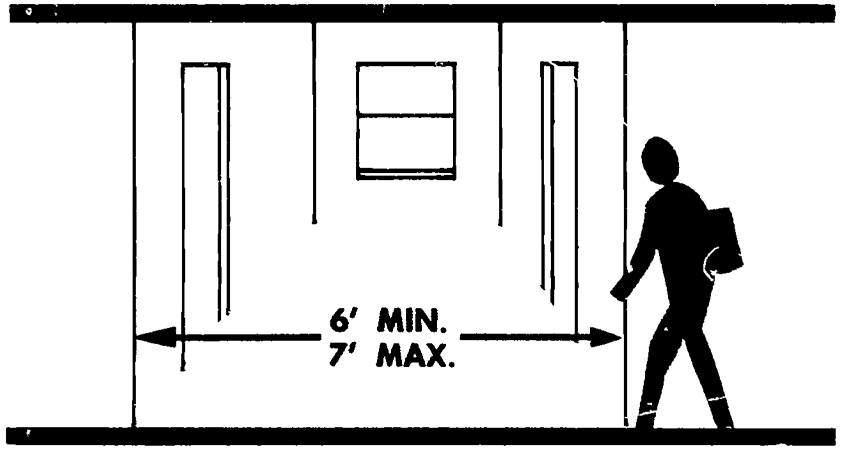
It is obvious that density of population is not nearly as significant a factor in non-classroom buildings as in buildings where large numbers of persons load the circulation facilities in limited intervals of time. Whereas a classroom typically provides 10–15 square feet per person, research and office areas may average 200 square feet per person.[1] Not only is the potential density here less than that of classrooms, but the population that uses the circulation facilities of other building types is distributed more evenly in time.

Therefore, if corridors in office or research buildings were designed solely to meet the demands of human traffic on the same basis as corridors in classroom buildings, the results would be quite unrealistic. Obviously a different set of conditions is operative. First, there is clearly a minimum width which enables two persons to pass one another comfortably. The codes usually consider this width to be 44 inches. Secondly, the relationship among corridor width, length and height may be influenced by aesthetic judgement to avoid corridors that, though legally and functionally designed, are oppressively narrow or low. This is largely a subjective matter, but the following formula, based on observation, is suggested as a rough guide:[2]

$$\text{where} \quad H : W = .035L,$$

$$\text{if } W = \text{width},\ H = \text{height, and } L = \text{length.}$$

The third factor concerns the movement and handling of equipment. In office areas this is not likely to be decisive in designing corridors, as most office equipment is made to fit through a door three feet wide or turn in a corridor four feet wide. But in research areas where custom-made, non-standardized equipment is common, corridors only four feet wide may cause difficulties. In hospitals 7'-0" is considered a minimum width because of the need for ease in swinging a bed 90°. This would appear to be a safe figure for research areas as well; it is difficult to conceive of a situation requiring greater width for research occupancy unless, of course, one wishes to consider the aesthetic factor as dominant in some particular instance. If 7′–0″ is the upper limit, the lower limit should probably be not less than 6′–0″, because of equipment handling requirements. Corridors in teaching laboratory areas, where densities (exclusive of preparation and storage spaces) average 30–60 square feet per occupant, can follow the recommendations applicable to research areas, for it is unlikely that the density method suggested for classroom areas would result in corridors greater than 7'-0" in width, even though station utilization may be very near 100 percent.



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[1] This figure includes storage, files, darkrooms, and net areas other than the principal work station of the researcher or office employee.

[2] Where a corridor is widened at specific points, e. g., at elevator banks, greater attenuation is possible in the basic width.

IV. *Vertical Circulation*

A. Stairs

In multi-story buildings without elevators, considerably more time is spent on the stairs than in the corridors. If the corridors were designed according to the recommendations in this study, a maximum of about 25 seconds would be spent by an individual walking from his room to the stair. But in an analysis of three four-story classroom buildings the average time spent on the stairs and landings, while descending unimpeded by traffic, was one minute and 25 seconds.

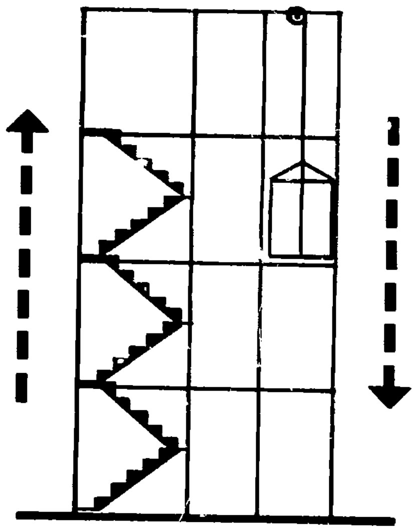
Another point worth noting in evaluating stair design standards is that adding two feet to the width of each tread may increase the size of a building by about one percent, whereas adding two feet to a corridor in a typical classroom building can increase the gross area by four percent.

Thus, whereas stairs rather than corridors are the inhibiting factor in circulation time, they are much less significant in cost. In loose terms, if corridors are designed minimally and stairs comfortably, the savings in corridor space will be more significant than the cost of expediting traffic through generous tread widths. For the architect this means alertness to possible overdesign in corridors, where any excess implies a heavy financial penalty because of the amount of space involved; and it means equal alertness to the dangers of scant design in stairs, where the cost factor is not as prominent as the possible hindrance to proper operation.

In stair travel as in corridor travel the key test is the ability of the stair to permit movement under peak load conditions at the same rate as would otherwise be maintained. In classroom buildings peak load periods coincide with two-way traffic movement. Where elevators occur the ascending stair load will probably be lighter, while in buildings without elevators we can only assume that half the width of the stair is devoted to descending half to ascending traffic.

On this basis it appears that 30 persons per 22 inch unit of stair width[1] are all that can be carried if normal walking pace is to be maintained. Thus, a single flight of a 44 inch wide stair can permit 30 persons to descend from a landing in close succession (for example, after leaving a classroom), while 30 others are simultaneously ascending from the next lower landing. As in the case of corridor planning, the 30 persons per unit of exit width must be considered as a percentage of capacity for planning purposes. Again assuming a capacity utilization factor of 66 2/3 percent, the planning standard to be derived from these observations will permit a population of 45 persons per unit of exit width.

In other than classroom buildings there is no significant problem of density or of two-way traffic. Stairs of 44 inch width will probably serve under any circumstances though, as will be seen later, it is frequently necessary to provide for greater width to meet code regulations.



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[1] The National Fire Protection Association, with the concurrence of most other regulatory bodies, uses the 22 inch module as a basis for stair design. It is stated that this optimizes the usefulness of the stair in that adding inches will not add to carrying capacity. An exception is made for increments of twelve inches. Thus stairs can be 44 inches wide, or 56 inches, or 66 inches, representing the ability to carry various numbers of people. The stairs would not be more useful if they were 48 inches, 60 inches, and 72 inches instead of the smaller widths.

A word should be said on the distribution of stairs within the total building. The procedure is usually to require stairs to be placed so that every occupant is within a maximum distance of 100-125 feet of a stair. Population is converted to total tread width and this total width is distributed among the two, three or more stairways. The point is that the division of total tread width need not be into *equal* parts. For example, if seven and one-half units of exit width are required, it may be cheaper in terms of framing and other elements of construction cost to plan three stairways with 56 inch treads. But the flow of traffic may be much better served if instead one 78 inch stair and two 44 inch stairs are provided.[1] Stairs should be planned in relation to present and *future* campus circulation patterns.

B. Elevators and Escalators

In treating this aspect of circulation the discussion which follows is in two parts: The first emphasizes the desirability of avoiding high rise buildings for heavy, i.e., student, vertical traffic. The second presents a general method for approaching the economic analysis of high rise construction where the physical circumstances of the institution impose verticality as a factor in transporting students as well as staff and materials.

Where elevators are required solely for the transportation of staff or materials the programming is routine and excluded from this study.

1. Limitations of Elevator and Escalator Transportation

Elevators may be considered as a device permitting more intensive use of available land. Increasing the height of the building permits a given ground area to serve more cubic feet of space. The number of elevators required to effect this increase is proportionate to the population to be transported, to the length of the interval of time allowable and the number of stories.

If a college's space requirements imply the erection of several additional buildings, and land cost dictates that at least some of these must be high-rise, or served by elevators, then the question to be resolved is the distribution of the college's activities among these buildings. The cost of elevators and/or escalators may well be the decisive factor in the development of such a building program. How this cost can be minimized is the subject of this discussion.

To begin with, it is clear that the more work the vertical transportation system performs, the more the installation will cost. The following example gives some idea of the proportion of the building dollar that may be committed to vertical transportation.

Assume a ten story building with a classroom capacity of 400 per floor or 4,000 students total. Assume a gross floor area of 10,000 square feet and a gross building area of 100,000 square feet.[1]

To transport 40 percent of the student station capacity in ten minutes will require an investment of about $1,500,000. This is the cost, probably minimal, of twelve large (7,000 pound capacity) passenger elevators, including hoistways.

To evaluate this kind of expenditure two questions should be asked and answered: What is

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[1] In many codes center rails are prescribed for stairs in excess of 88 inches. This useful provision will not effect the validity of the proposal stated above.

[1] This calculation is based on 400 classroom stations at a maximum of fourteen square feet each, plus additional net area to bring the total net area per floor to between 6,000 and 6,500 square feet. This will require a gross area of about 10,000 square feet.

[2] An elevator of this size can carry 47 persons but in practice the average load would be about 33 persons.

the ratio of elevator cost to building cost, and how efficient is the performance of the elevators?

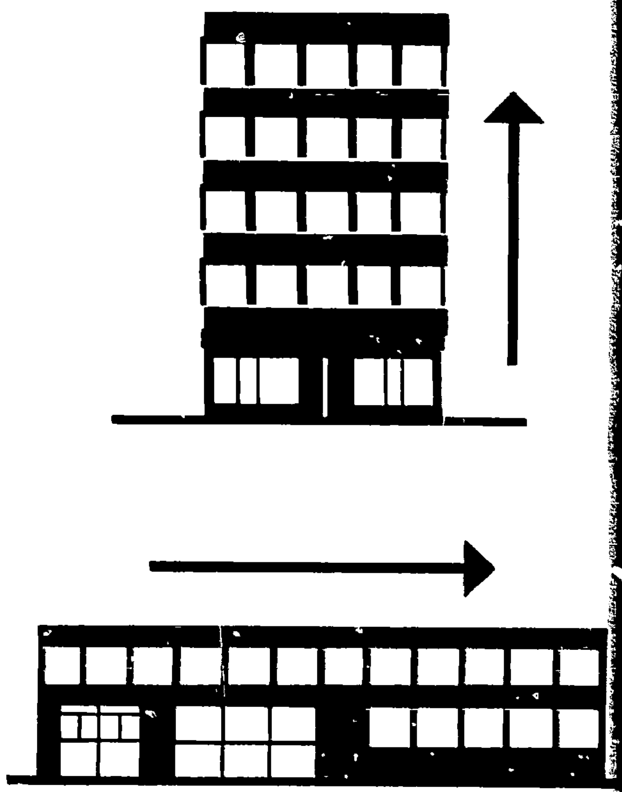
The total construction of the building in the example, without elevators, would be in the range of $2,000,000—$2,500,000, even if the gross area were distributed over three or four stories. Converting the same functions to a high-rise, elevator equipped building would thus add 60 percent to the cost. This additional expenditure would presumably be offset by savings in land and, to a small extent, by savings in stairwell area.[1]

The efficiency of this installation is open to serious question. The ability to carry only 40 percent of the student station capacity in the class break intervals is not necessarily unrealistic in itself. It is the equivalent of 60 percent of the population postulated earlier, that is, 60 percent of two-thirds of capacity. Why doesn't the remainder of 40 percent of the students require elevator service? Presumably because they use the first or second floor, or remain on the same floor that housed their preceding class, or because moving between classes involves a change of only one or two levels. The real problem arises in that a full ten minutes is required to transport the 1,600 students who would ride in the elevators. The man on the tenth floor will probably require two minutes and 45 seconds to leave the building but, depending on the distribution of the load, he may not even be that lucky.[2] In any case the trip takes almost twice as long as a walk down or up from the first to the fourth floor on a properly sized stair.

Why should it cost so much to accomplish so little? The elevator has proved its worth in many situations. The problem here, of course, is the same as on the stairs—two-way traffic in concentrated intervals. In office buildings the peak loads at 9 AM and 5 PM are essentially one-way affairs, so that the round trip interval is reduced and the carrying capacity of the system is correspondingly increased.

For colleges the heart of the problem is not the relationship of elevator cost to ground cost per se. It is the ratio of building volume to number of elevators. Heavy concentration of population should be restricted to the four lowest levels, to be served by the stairs. Upper floors should be devoted to such activities as faculty, staff, and graduate student research, not necessarily related to the lower floor activities. Thus a ten story building with four floors of classrooms and six of research having 20,000 square feet per floor could be served by two or three passenger elevators and one freight elevator. Only one of the passenger elevators would have to stop at intermediate floors between the first and fifth.

This type of juxtaposition of heavy and light densities has been tried successfully outside the campus. For example, a skyscraper hotel was recently constructed on top of two low-rise department stores. The hotel elevators utilized a small lobby on the first floor but otherwise all hotel activities began above the highest level of the stores, with which the hotel had no physical or operational connection. This type of arrangement would provide a number of corollary advantages to the university. It would make possible a wider geographical distribution of classroom space, reducing the time spent in circulation between buildings. It would provide greater privacy for research or office activities by removing them



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[1] The savings in stairwell area would at most equal the increment between the stair width as determined by code and as recommended in the previous section of this report. It is very doubtful if this increment would exceed one percent of the gross area of the building.

[2] The average waiting time is 45 seconds. Two minutes are consumed for the travel time of the elevator in its descent, allowing time for stops.

from the noise of campus level traffic. For departments requiring teaching laboratory space a logical arrangement might be to place general purpose classrooms on the lowest levels, teaching laboratories in the middle and research activities on the upper floors.

Escalators, for certain combinations of building height and student population, can carry more passengers for less money than elevators. In the examples of the ten-story classroom building, previously cited, savings through the use of escalators to the sixth floor, reducing the required number of elevators, might be about ten percent.

In buildings of six or seven stories, the most desirable maximum height for escalators, the difference between elevator cost and escalator cost may be considerably greater. Nevertheless, the escalators can still represent a very substantial fraction of the gross building cost, all of which may be eliminated if the student traffic generated by classrooms and teaching laboratories is held to the first four (or five, including basement) levels.

The field survey tended to confirm these observations on the limitations of elevator travel in classroom buildings. For example, the time required to leave the fourth floor of a seven-story classroom building was consistently greater when the elevator was used, despite the fact that only about 20 percent of the station capacity chose to ride. The average time required for ascent to the fourth floor at four different hours was also greater when the elevator was used, although one of these trips took fifteen seconds less than the fastest stair time.

2. An Approach to Economic Analysis of Transportation in High Rise Buildings

Despite the desirability of eliminating elevators and/or escalators for carrying students, there will be instances where this goal is impossible of achievement. For example, elevators to serve all floors may well be essential in urban institutions comprising one or only a few buildings, with the bulk of the space in classrooms and teaching laboratories. The problem then may be to determine the most economical amount of land to use for a given volume of construction. If the area available is adequate and land costs are sufficiently low, the building may be kept down to four or fewer stories, thus requiring only a service elevator. On the other hand land cost may imply a taller building on a smaller site, which may be feasible only if elevators are installed. The appropriate decision is actually a function of the interaction of land cost and building cost. Building cost (if volume is constant) is affected by the presence and nature of elevators and by such other factors as may be a function of shape rather than bulk. Finally, elevator arrangement for a building of given volume and shape is a function of the size and activity patterns of the population.

These relationships cannot be expressed in dollars except for a specific, individual instance. The range of variables is too great to permit generalizations on cost. For example, the elevator or escalator system in a building is not a standardized component but a custom tailored installation which in itself contains such variables as the size, speed and number of its components.

Therefore the most useful approach is one which permits generalization on the method for evaluating alternate possible architectural solutions, leaving the quantitative solution to be worked out in terms of the conditions posed by a particular building process. To this end, an algebraic statement of the relationships among the principal factors in a high rise building project is presented below. The exposition, which assumes a full cost-life of system analysis, is deliberately simplified; such annual costs as taxes, amortization and maintenance are not expressly defined but included in the broader components noted below. The objective, of course, is to find the least cost alternative for any given building program. Algebraically, the optimum or least cost situation may be expressed as

(1) $(\Sigma C)_1 \; (\Sigma C)_2 \; . \; . \; . \; (\Sigma C)_n$

for any one building, where ΣC is the sum of the costs and subscripts 1...n represents the various possible solutions listed in ascending order of costs.

For purposes of this model ΣC may be defined as

(2) $\Sigma C = C_L + C_B + C_E$

where C_L is the cost of land, C_B is the cost of building (excluding elevators or escalators) and C_E is the cost of elevators and/or escalators.

Since the concern here is with the relation between land use and building height for a fixed volume of usable space, the problem may be considered in terms of the number of floors required under specific constraints. For any one possible solution the cost per floor may be expressed as

(3) $\frac{\Sigma C}{N} = \frac{C_L}{N} + \frac{C_B}{N} + \frac{C_E}{N}$

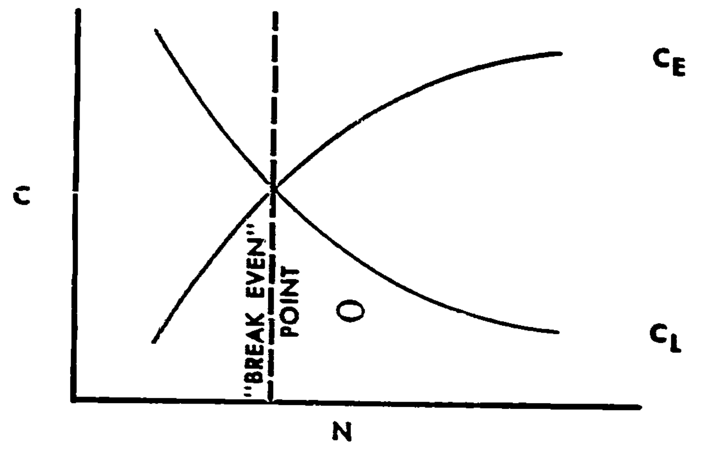
where N = the number of floors.

Among several proposals involving differing heights the "break even" point in sacrificing land to height may be stated as

(4) $O = \Delta\frac{C_L}{N} + \Delta\frac{C_B}{N} + \Delta\frac{C_E}{N}$, or

(5) $-\Delta\frac{C_L}{N} = \Delta\frac{C_B}{N} + \Delta\frac{C_E}{N}$

where Δ is the increment of change. Typically, the incremental land cost per floor diminishes as as the incremental elevator and/or escalator cost per floor increases; therefore, at some point they will be in balance and it will be possible to determine the building height which results in the minimum aggregate construction cost. This is expressed algebraically in equation (4) and is represented graphically below.



Each of the cost elements in equation (5) may then be expressed as a unit cost multiplied by a quantity.

(6) $-\frac{\Delta(P_L)\,\Delta(L)}{\Delta N} = \frac{\Delta(P_V)\,\Delta(V)}{\Delta N} + \frac{\Delta(P_E)\,\Delta(E)}{\Delta N}$

where P_L is the unit price of land, L is the amount of land, P_V is the unit price of building (exclusive of elevators and or escalators), V is the volume of construction, P_E is the unit price of elevator and or escalator capacity, E is the amount of circulation capacity and N is once again the number of floors.

This model can be expanded further to take account of the many additional components and relationships to be found in actual practice. It can also be used to compare alternate circulation systems, as well as variations in a single type of circulation system.

V. Code Requirements

A. Corridors

Building codes are promulgated by state and local authorities in order to safeguard life and property. In addition groups identified with the writing of insurance have also prepared codes which, though without the force of law, have influenced the drafting and revision of government codes for the past 50 years.[1] The insurance codes gain additional status because failure to conform to their requirements can result in higher premiums, whether or not one is adhering to the legal regulations of the locality.

As the codes are concerned with safety in case of fire or other emergency, almost all of them provide detailed specifications on the subjects of corridors and stairs. However, though there is general agreement on objectives, there is a very wide diversity on the details prescribed. The underlying objective of these regulations is the setting forth of conditions whereby the occupants of a building can evacuate any room quickly and proceed through corridors and stairs to the outside in safety. The specifications for the corridors, stairs and other critical features of the building vary with the type of construction, the size of the building, the use or type of occupancy and the number and location of persons to be served. These specifications state, directly or indirectly, the amount and nature of circulation space per occupant.

One of the problems that arises here was touched on before: defining the number of occupants while the building is in the design stage. There are many formulas in use, those applicable here being usually listed under a section of the code entitled "educational occupancy." The provisions of some typical codes are listed in Table 2. It should be noted that some codes provide formulas specifically for classrooms while others do not. Presumably the authors of the codes have selected occupancy formulas designed to provide a margin of safety. Nevertheless, in many classroom buildings there are far more seats available than would result from dividing the gross area by 40 square feet, the formula used in the National Board of Fire Underwriters and National Fire Protection Association codes. Even if one assumes that only two-thirds of the seats are filled the building may actually have more persons present than are theoretically provided for in a number of these codes.[1] On the other hand, when most of these formulas are applied to research space the population and, correspondingly, the corridor and stair area will be considerably overstated.

It is useful to compare the corridor and stair area that would result from applying a code formula to a specific example with the area corresponding to the recommendations in the preceding sections of this study. The code selected is the NFPA Building Exits Code, 1960 edition, which

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[1] Most notably, the National Board of Fire Underwriters and the National Fire Protection Association.

[1] The code describes the population derived from the stated occupancy formula as a minimum and prescribes using the maximum capacity of classrooms where this will result in a wider corridor.

is used because many institutions which are exempt from local codes have adopted it as a standard.

Let us assume a building 200 feet long and 54 feet wide. The population as determined by the code would be 270 persons per floor. The corridor would be 22 inches wide for each 100 persons. In this case a corridor 66 inches wide would be required. The total corridor area would be 197'-0" x 5'-6" or 1084 square feet. This is equivalent to 4.0 square feet per person. If the full student station capacity of 490 were used instead of the formula minimum, the result would be five units of exit width or 9'-2", or 3.7 square feet per person.

Using the method of calculating corridors recommended in the preceding section, the total of 490 student stations would require corridor space as follows:

490 x 4.0 (sq. ft./person) = 1960 square feet.

If 1960 square feet is divided by the length of the corridor, the result is five and one-half units of exit width or 10'-2". This is one foot wider than required by the NFPA code, using the full station capacity.

In Chicago the *net* area of the floor is divided by 20 to establish classroom occupancy. This would result in 336 persons. The Chicago code permits 115 persons per unit of exit width, so 66 inches would be the resultant corridor width. In Indiana an 8'-0" minimum corridor width is required, while the occupancy formula for classrooms is one person for each 18 net square feet. In New York 15 square feet is used and in Wisconsin 10 square feet, which would produce over 600 students in the example shown. Some states require occupancy in "lecture halls" to be calculated

TABLE 2. Comparison of Building Requirements—Corridors and Stairways[a]

Code	Maximum Travel Distance to Stairway (feet)	Standard for Calculating Width (persons per unit of exit width)[b] Stairways	Corridors	Minimum Width of Corridor (inches)	Occupancy Formula: Minimum Requirements (square feet per occupant)
Chicago	100[c] 150[d]	115	100	60[e]	20, classrooms, recreation rooms, libraries; 30, laboratories and shops; 6, other assembly uses
Indiana	125	100	100	96	18, classrooms, recreation rooms, etc.; 25, laboratories, museums, libraries; 40, shops, vocational rooms; 12, gymnasiums; 6, lecture rooms, assembly rooms and the like
New York City	125	30	44 inches minimum for first 50 persons plus 6 inches for each additional 50 persons[f]		15, classrooms; 25, laboratories
Ohio	100	100	100	34	gross area of building/40 square feet
Wisconsin	100	100	100	48	10, classrooms
National Board of Fire Underwriters	100	60	80	36	gross area of building/40 square feet
National Fire Protection Association	125	60	100	60	gross area of building/40 square feet

[a] This table details only the principal specifications for the categories listed, so that the range of variation can be noted. Differences in the definition of terms or in methods of measurement are not shown. Where the code lists a general regulation and one applicable to schools, only the latter is shown in the table.

[b] A unit of exit width is defined as 22 inches by all codes noted here except Wisconsin. In this state a unit of exit width is 30 inches. For a further explanation see the discussion in the text.

[c] For floors at grade only.

[d] For upper floors.

[e] This figure applies to classrooms and similar uses; otherwise 44 inches is acceptable.

[f] The minimum corridor must also be equal to 69 percent of the aggregate width of stairways.

on a basis of one person for every six square feet. Surely a very fine distinction exists between a "classroom" and a "lecture hall" on a college campus.

It would appear that in most codes, when schools are mentioned, the provisions derive in the main from situations prevailing in primary and secondary schools. Though colleges are usually specifically included as "schools", their special characteristics have not often found expression. This problem applies to requirements for other features of college buildings, such as toilet fixtures, as well as to the calculation of occupancy for exit facilities.

B. Stairs

The codes are no more unanimous on the subject of stair widths than they are on corridor requirements. In addition to the range of formulas used in calculating occupancy, the number of persons permitted per unit of exit width is subject to variations. (See Table 2.) It is impossible to to evaluate these regulations except by conducting the type of tests which relate to the objective of the code prescriptions, that is, safe evacuation during an emergency. There is reason to believe that the NFPA code, which is revised more frequently than the others and which is based on the research of representative staffs and committees, is the most reliable in providing for safe exit without undue waste of space. Nevertheless their specification is not adequate to the volume of two-way traffic typical of college classroom buildings.

The recommendation suggested earlier, 45 persons per unit of exit width, represents a 50 percent increase over NFPA requirements, if difference in occupancy calculations are disregarded. Only New York City, of the codes listed, requires lower densities on stairs.

VI. *Summary and Conclusions*

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The principal findings of this pilot study are summarized in Table III. In concluding it may be useful to place these recommendations in the context of campus-wide circulation patterns.

In the first place the most severe pressure point in the area of circulation is probably the inter-building time-distance factor rather than the intra-building facilities which comprise the scope of this study. If the desirability of limiting the time between classes to ten minutes is accepted, then the question arises as to how much of this interval is to be spent on the stairs and in the corridors and how much time remains for travel between buildings. There appears to be no reason why the time from the classroom to the street or the street to the classroom should exceed two and a quarter minutes. If the student must go from the fourth floor of one building to the fourth floor of another he will probably have between five and one-half and seven minutes available for inter-building travel. A very considerable variation from good practice in corridor and stair design would be required to result in reducing the inter-building time to less than five minutes. On the other hand corridor and stair design cannot serve to make more than seven minutes available for inter-building travel because of the limitations of the pedestrian's average speed on stairs.

This is not to suggest that the design of corridors and stairs is unworthy of close attention. Their cost alone would make it important for these elements to be programmed efficiently. But a more significant factor in planning circulation, particularly in the present period of expansion, is the amenability of class schedules and of physical plant to the purpose of limiting the distances travelled between classes.

Scheduling is really the key to a number of campus operational situations. One object of scheduling should be to distribute the class meetings as evenly as possible throughout the teaching day and week. It is the peak resulting from unevenly applied workload that results in excess demand for space at the same time that circulation is overburdened. The university will probably attempt first to equalize the demand for space over the hours from 8 AM to noon. Then more intensive use of afternoon hours begins. Then evening time for scheduled classes and laboratories becomes more common for day students.

It is possible that some more radical techniques for accommodating greater enrollment may be required if oversaturation of campus facilities is to be avoided. One such proposal, which would reduce the peak loads on circulation and other facilities may be termed the staggered schedule. Students on the "A" schedule would begin classes on the half-hour, students on the "B" schedule would begin on the hour. For single section advanced courses "A" students might have to take "B" courses, but in the main the number of "A" and "B" sections could be approximately equalized without loss of student time. Such an arrangement would halve the peak demands on corridors, stairs, elevators and intra-building circulation facilities. In addition it could ameliorate the problems of overcrowding incident to access roads in the morning and to dining facilities at noon. In essence the problem is to minimize the heaviest demands on campus facilities by distributing these demands more evenly and more widely through time.

TO MAKE BETTER, MORE TOLERABLE

Whatever the merits of such an arrangement, it recognizes the interdependency of physical plant efficiency and operating methods. It is in the area of this relationship that we may look for the most significant gains in campus planning technique.

TABLE 3. Summary of Findings on Circulation Facilities in College Buildings for Instruction and Research

Type of Space (1)	Formula for Occupancy (2)	Recommended Corridor Width[a] (3)	Recommended Stair Width[a] (4)	Desirability of High Floor Location[b] (5)
Classrooms	66.67% of station capacity	4.0 square feet per station	45 persons per unit of exit width	Undesirable
Teaching laboratories	100% of station capacity	6'–0" to 7'–0"	45 persons per unit of exit width	Undesirable
Research laboratories	100% of staff and students	6'–0" to 7'–0"	3'–8"	Desirable
Staff offices	100% of staff	3'–8"	3'–8"	Desirable

[a] Based on use of occupancy formula in Column 2.

[b] This column has reference to the desirability of locating the various types of space above the fourth story in high-rise buildings, implying the use of passenger elevators.

Appendix

EXHIBIT 1

INSTRUCTION SHEET FOR SURVEY OF CIRCULATION FACILITIES

I. Record the following observations during class sessions:

- a. Total number of student stations available for each classroom
- b. Number of classrooms in use at each hour
- c. Total number of students present at each hour
- d. Number of risers per flight for each story from survey floor to street
- e. Time (walking) from remote point on floor to
  - 1. Each stair
  - 2. Street
  - 3. Remote point on floor below
- f. Time from street to
  - 1. Point of intersection of stair and corridor
  - 2. Remote point on floor

II. Record the following observations during class changes:

- a. Time from remote classroom door to
  - 1. Each stair
  - 2. Street
  - 3. Remote point on floor below
- b. Time from street to
  - 1. Point of intersection of stair and corridor (for each stair)
  - 2. Remote point on floor

III. Simultaneously with II record by counter the number of persons passing intersection of corridor and stair while

- a. Leaving the floor
- b. Entering the floor

IV. Record the following observations during class changes:

- a. Number of persons ascending each stair, as observed on landing immediately below floor being surveyed
- b. Number of persons descending each stair, as above

V. Simultaneously with IV record by counter the number of persons passing intersection of corridor and elevators while

- a. Leaving the floor
- b. Entering the floor

VI. Record the following observations during class changes:

- a. Time from remote classroom door to
  - 1. Elevator or elevators
  - 2. Street (by elevator)
- b. Time from street by elevator to
  - 1. Point of intersection of elevator and corridor
  - 2. Remote point on floor

The field survey described in Section II made use of the form reproduced here (Exhibit 2). Each form is applicable to one floor of a building, but information on each stair requires a separate sheet. This form is designed to be used in conjunction with an instruction sheet (Exhibit 1). In order to secure the information desired the survey team should number one person more than the number of stairs, in buildings without passenger elevators and two persons more than the number of stairs in buildings with passenger elevators. Automatic counting devices and stopwatches should be used; it is also desirable for the person in charge of the survey team to have a plan of each floor. Each floor should be surveyed at least twice for each hour of the morning.

NOTES TO ACCOMPANY INSTRUCTION SHEET

A. Results of observations as indicated on instruction sheet should be recorded opposite appropriate paragraph notation on Field Date Sheet. Use a separate sheet to list the number of students present in each classroom and list only the total for all classrooms on the floor opposite item 1c

B. For section 1 of instructions observer times his own average walking speed by stopwatch during <u>un</u>crowded period, i.e., between class breaks. "Remote" point on floor is classroom door farthest from any stair.

C. For section 11 the observer walks with the group entering or leaving the floor at the average rate of progress of the group. Begin walk from street at mid-point of class break.

D. For sections V and V1, which relate to elevator traffic, "remote" points different from those used in 1, 11, and 111 should be established.

EXHIBIT 2

Field Data Sheet - Circulation Facilities

Item	Time		Number
	Min.	Sec.	
1 a			
b			
c			
d			
e 1			
e 2			
e 3			
f 1			
f 2			
11 a 1			
a 2			
a 3			
b 1			
b 2			

Item	Time		Number
	Min.	Sec.	
111 a			
b			
1V a			
b			
V a			
b			
V1 a 1			
a 2			
b 1			
b 2			

Institution:

Date:

Building:

Hour:

Floor:

By:

Stair Number:

Committee on Institutional Cooperation

This is a voluntary organization of the following eleven middle western universities: University of Chicago, University of Illinois, Indiana University, State University of Iowa, University of Michigan, Michigan State University, University of Minnesota, Northwestern University, The Ohio State University, Purdue University and The University of Wisconsin. Officially named the "Committee on Institutional Cooperation of the Council of Ten and the University of Chicago," the unit grew out of a series of informal meetings of the presidents of the universities and was formally constituted in 1957. The Committee is made up of one representative from each institution, appointed by his president. A small professional staff carries out the programs approved by the Committee.

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After the Committee was established, it requested and was awarded a grant from the Carnegie Corporation of New York to carry on its work. This grant extends through 1963. Staff offices are located on the campus of Purdue University at Lafayette, Indiana.

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In 1960, the Committee on Institutional Cooperation was awarded a special grant from Educational Facilities Laboratories, Inc. to facilitate cooperation among the eleven universities in programs for expansion of their building and educational facilities in anticipation of greatly increased enrollments projected for the 1960's. The Research Center was then organized, located on the campus of The University of Wisconsin at Madison to: (1) Serve as a clearinghouse for information about educational facilities among the eleven institutions, (2) Serve as a central repository for educational facilities research gathered from national sources relevant to the interests of the eleven universities, (3) Conduct facilities research on matters of common interest, and (4) Make available to other educational institutions information about outstanding practices already employed in any one or more of the eleven universities, or which may be developed under the grant.

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