Elevators

9.1 <u>Vertical Transportation System</u>

The vertical transportation system in a typical building consists of: (1) Service and freight elevators

(2) Passenger elevators.

The cost of such a system for a modern building is about 10% of the total building cost.

9.2 Ideal Performance of an Elevator System

The ideal performance of an elevator system is characterized by:

(1) minimum waiting time for a car at any level.

(2) Comfortable acceleration.

(3) Rapid transportation.

(4) Smooth and rapid retardation.

(5) Rapid loading and unloading.

(6) Quick and quite power operation of doors.

(7) Good visual floor indications.

(8) Easily operated car and landing buttons.

(9) Quite and safe operation of mechanical equipment.

(10) Comfortable lighting.

(11) good ventilation.

9.3 Types of Elevators

There are two types:

traction-type and hydraulic.

9.4 Major Elevator Equipment

The major equipment of a traction type elevator is shown in Fig. 9.1. These are:

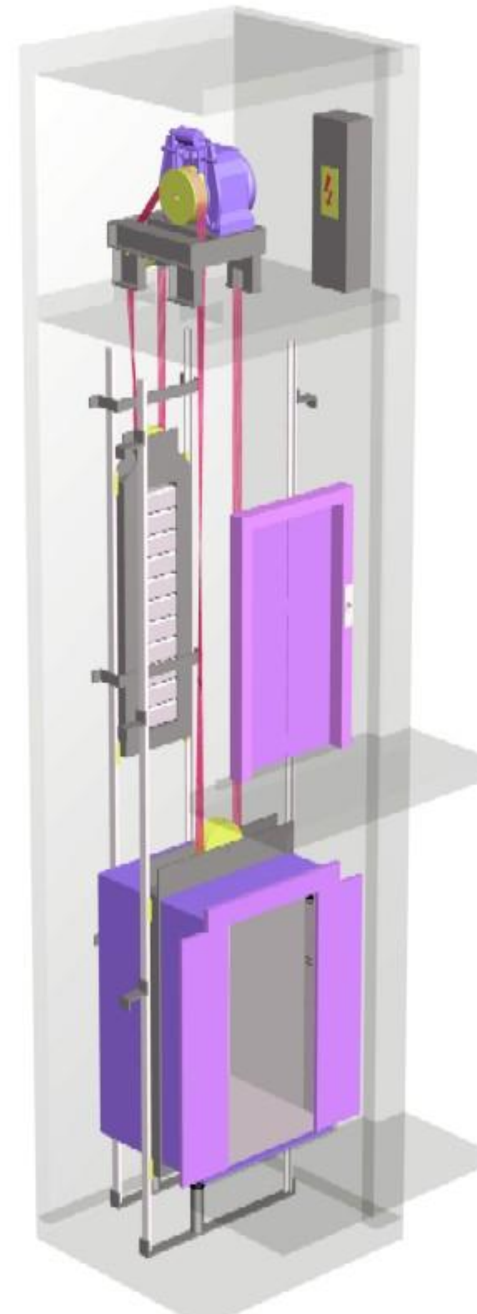
(1) Car.

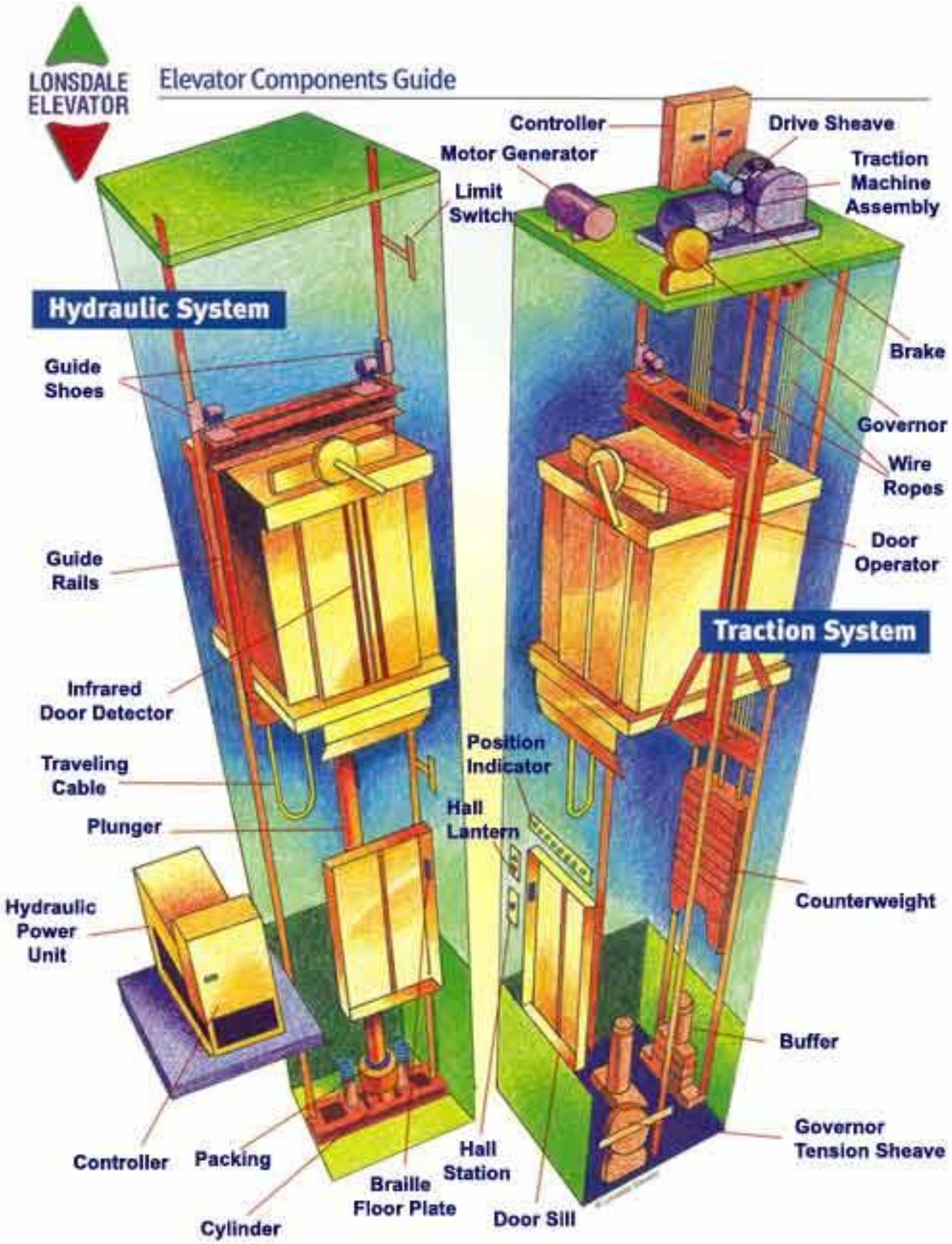
(2) Cables.

(3) Elevator machinery (generator, motor, controller,..etc

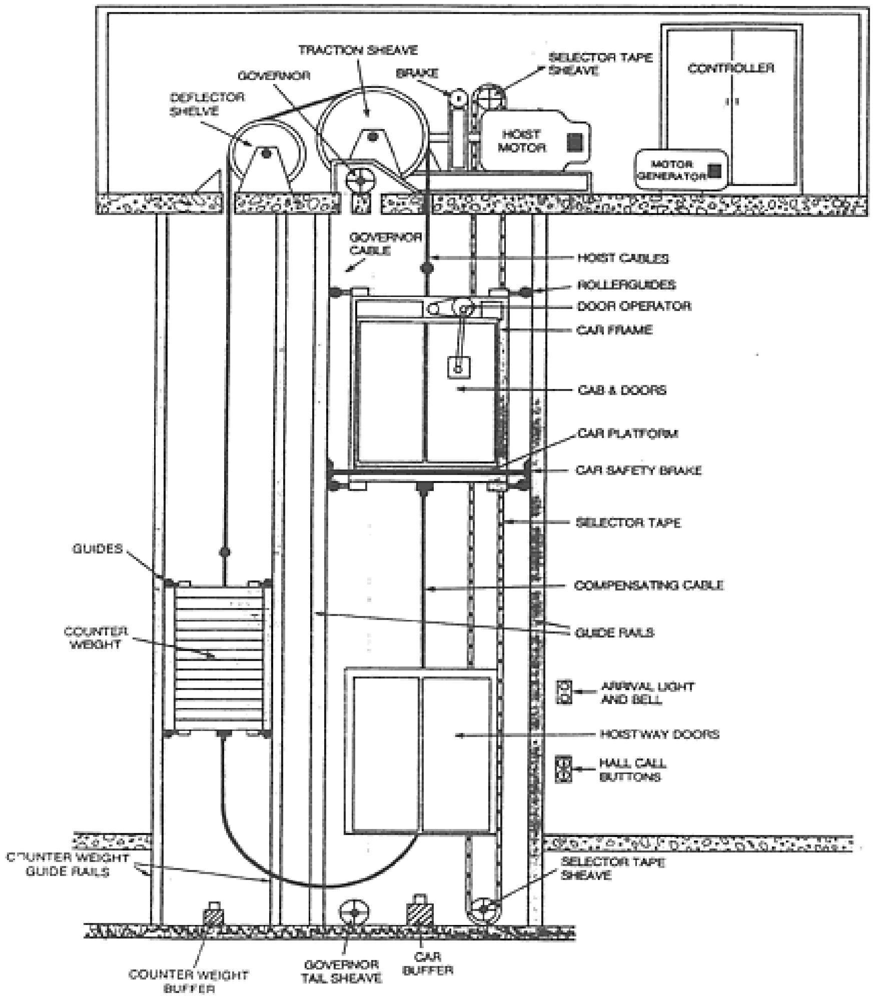
(4) Counter weight.

(5) Guide rails.





LONSDALE ELEVATOR
Elevator Components Guide
Hydraulic System
Guide Shoes
Guide Rails
Infrared Door Detector
Traveling Cable
Plunger
Hydraulic Power Unit
Controller
Packing
Cylinder
Braille Floor Plate
Hall Station
Door Sill
Hall Lantern
Position Indicator
Limit Switch
Motor Generator
Controller
Drive Sheave
Traction Machine Assembly
Brake
Governor
Wire Ropes
Door Operator
Traction System
Counterweight
Buffer
Governor Tension Sheave



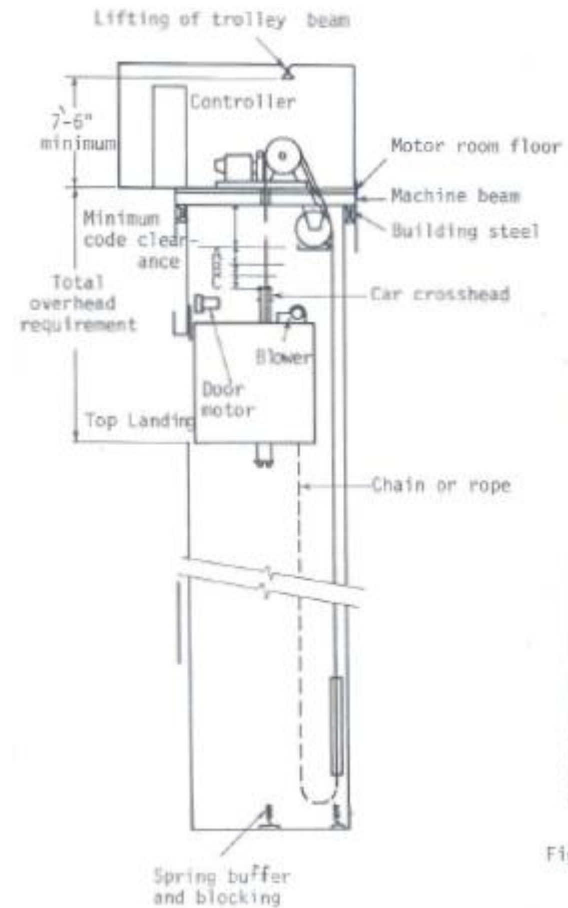


Figure 9.1: Traction-Type Elevator

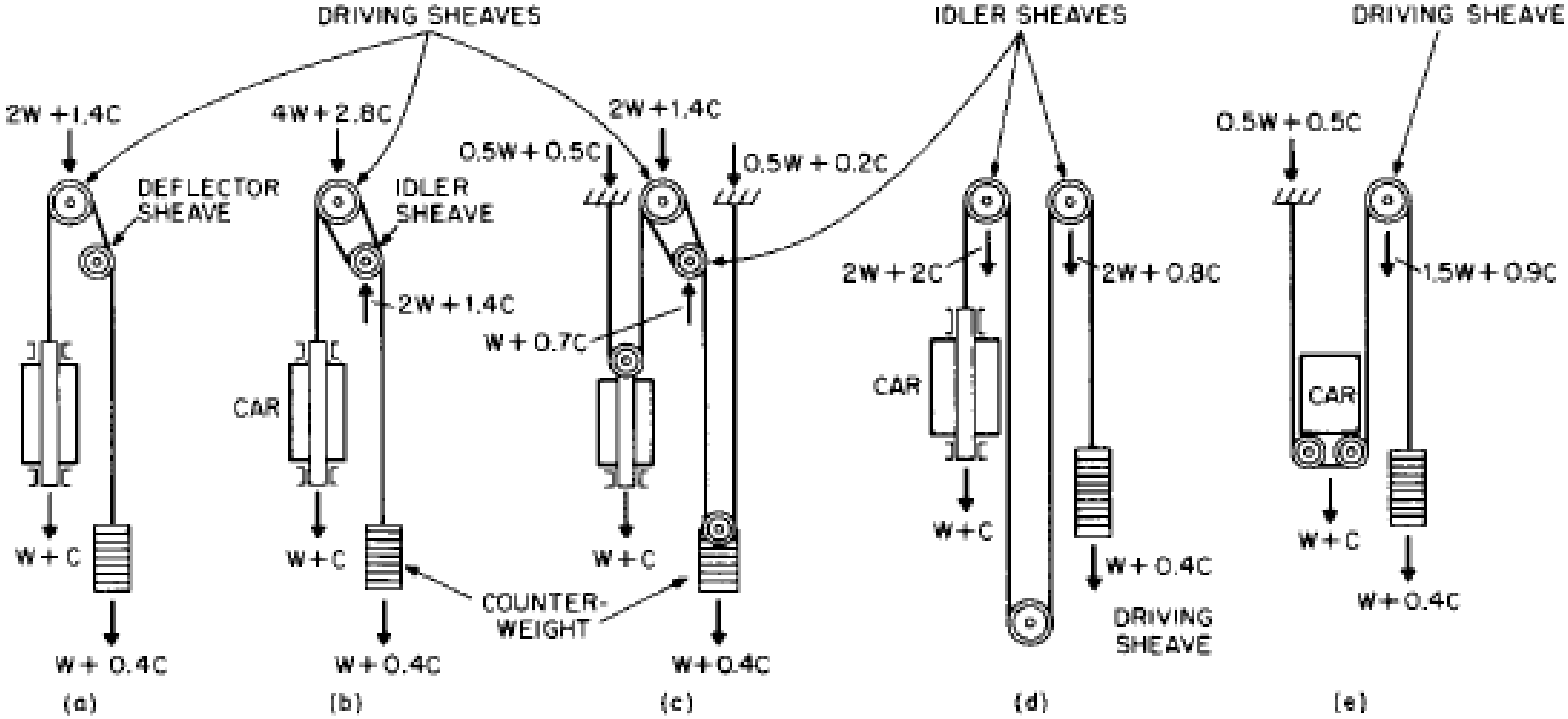
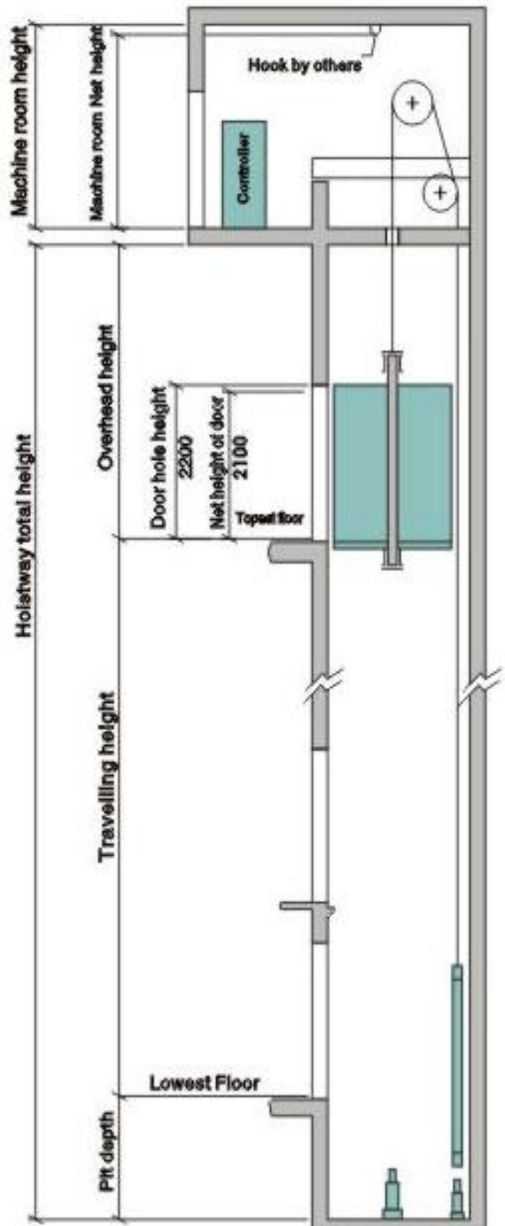
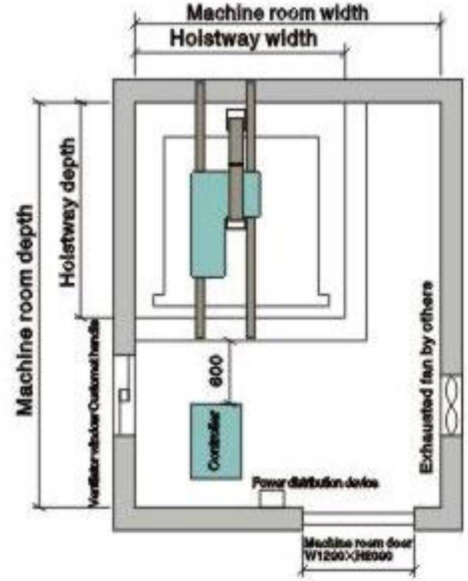


FIGURE 16.14 Types of roping for electric traction elevators. Rope tension and loads imposed on sheaves and supports depend on the type of roping, car weight *W*, and car capacity *C*.

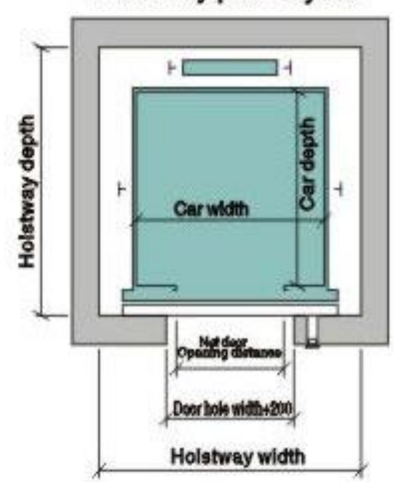
Hoistway vertical section



Machine room plan layout

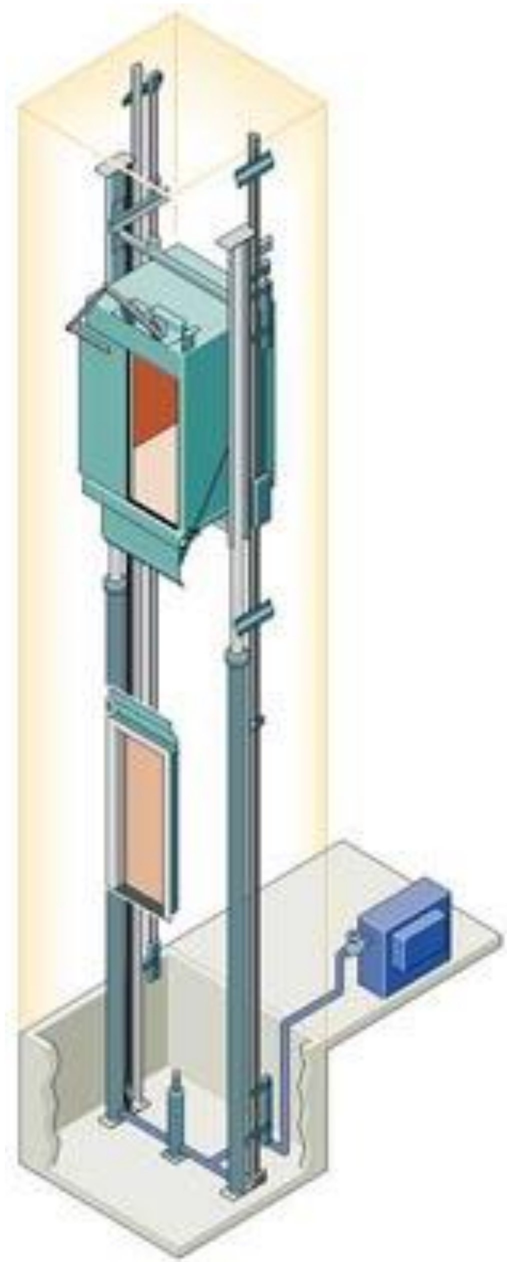


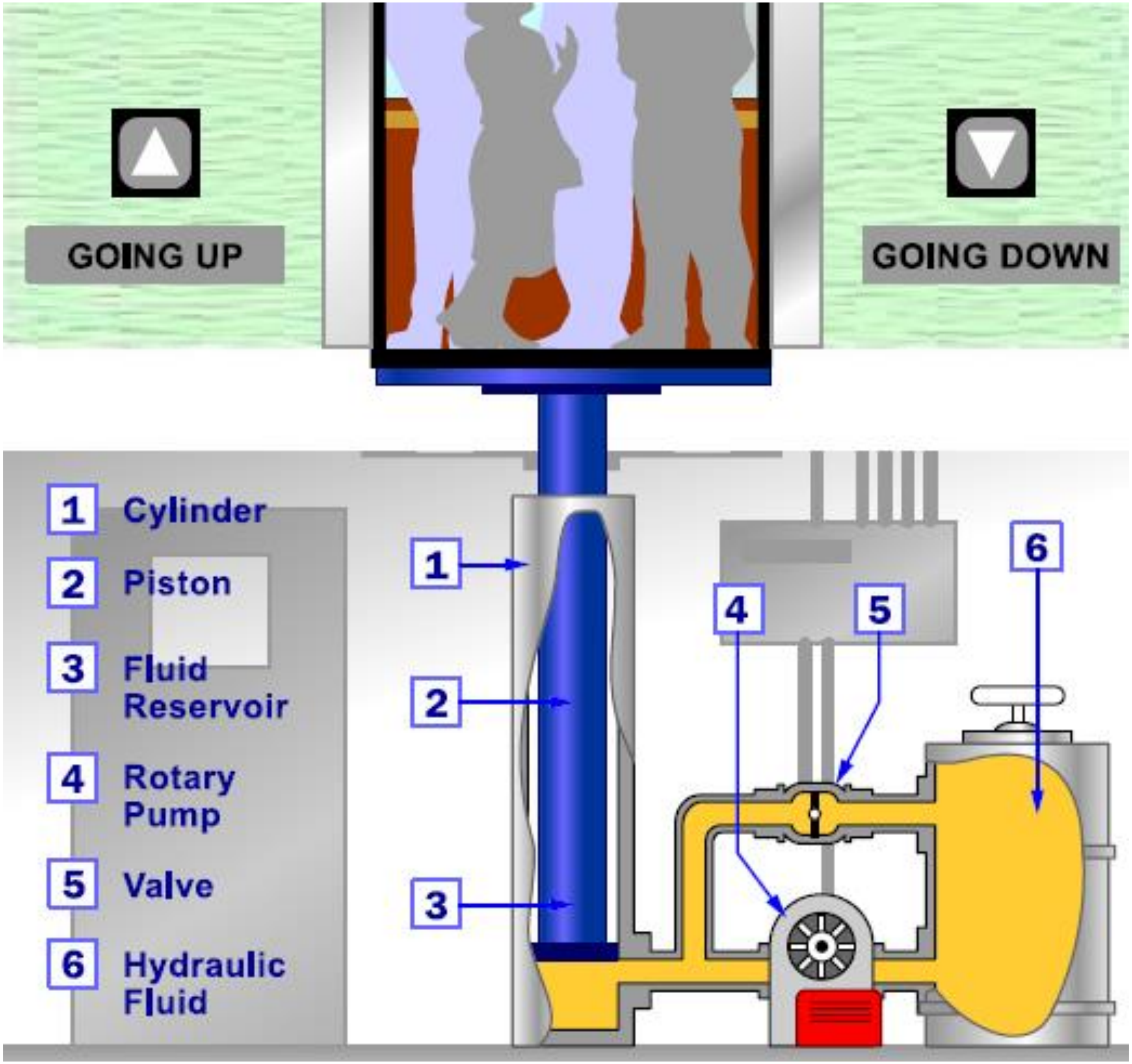
Hoistway plan layout



Hydraulic Elevators

- Uses hydraulics to raise and lower car
- Equipment room location varies, but usually located adjacent to the hoistway on the lowest level
- 3 Basic configurations: holed, hole less, or roped hydraulic
- Major Components: Hydraulic pump/motor, oil reservoir, controller, jack/jack related equipment, cab, hoistway, doors





GOING UP
GOING DOWN
1 Cylinder
2 Piston
3 Fluid Reservoir
4 Rotary Pump
5 Valve
6 Hydraulic Fluid
1
2
3
4
5
6

energy in lifting and lowering the car. The major equipment of the hydraulic elevator are:

(1) Car.

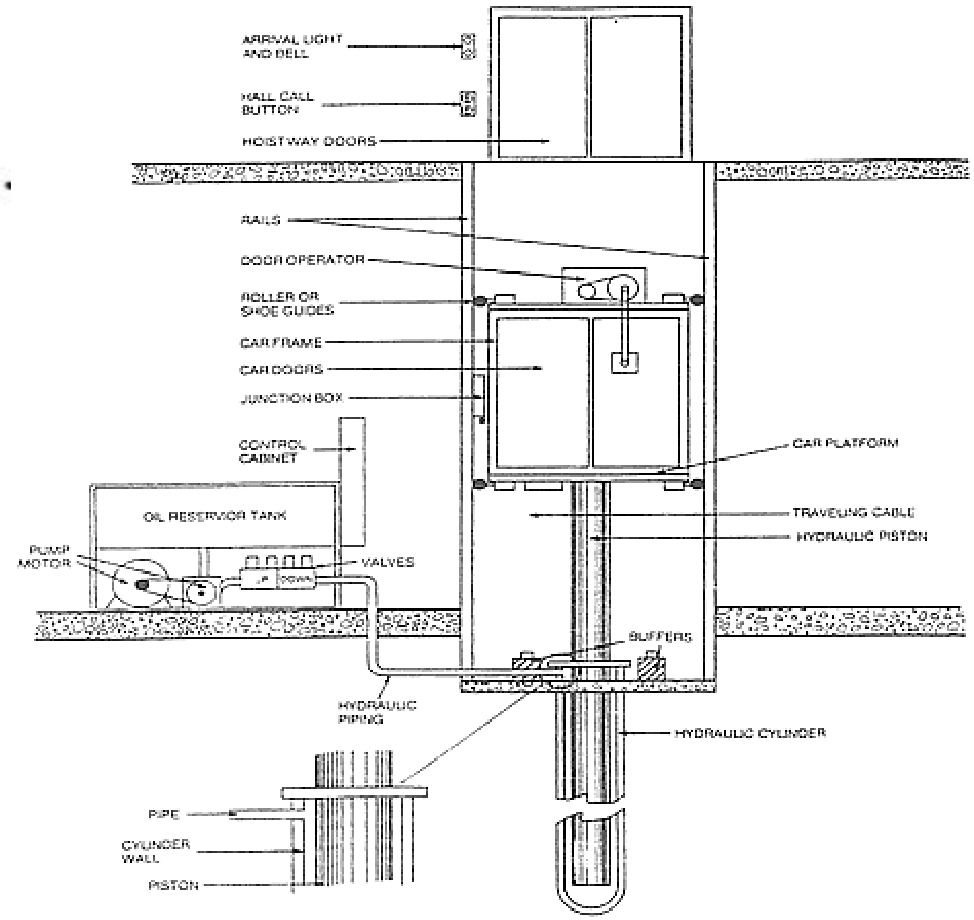
(2) Plunger.

(3) Piston-cyliner arrangement.

(4) Pump.

(5) Control valves.

as shown in Fig. 9.2.



9.5 Comparison Between Hyraulic and Traction-Type Elevators

(1) Hydraulic elevators are much simpler than the traction-type because of the absence of cables, chains, counter weights, drums, elaborate safety devices, penthouse room and its equipment.

(2) Hydraulic elevators are cheaper.

(3) Hydraulic elevators exert very little stresses on building structure and therefore are good choice when the absence of the penthouse is desirable (may be due to certain load conditions).

(4) Hydraulic elevators have higher weight carrying capacity.

(5) Hydraulic elevators are much slower than traction type. The maximum speed of a hydraulic elevator is around 200 fpm

(6) Hydraulic elevators need deep pit in the ground.

(7) Hydraulic elevators do not have counter-weights and therefore need much larger motor (for pumping oil) i.e. their running cost is higher.

(8) Hydraulic elevators are limited to low-rise applications (upto 75 ft).

9.6 Architectural Requirements for Elevators

(1) A machine room at the top of building is required for traction-type elevators. This room should have good ventilation to get rid of the heat generated by power equipment.

(2) A space for the elevator shaft that can be integrated with the building design.

(3) A minimum top clearance and a minimum bottom clearance. The bottom of the shaft has a buffer spring (to stop a falling car gently).

9.7 Space Considerations and Elevator Arrangements

After calculations are made to determine the number and size of the elevators, the important task of their arrangement remains. In doing so, the following considerations should be taken into account:

(1) Elevators cores should be centralized with respect to the building. The distance from the elevator core to the farthest space should be less than 150 ft or 50 m as shown in Figs. 9.3.

(2) When two elevator cores are considered, they should be arranged grouped together to avoid passenger indecision as demonstrated in Fig. 9.4 and to avoid delay of service if an elevator is tied up by movers or the like.

(3) The arrangement of cores should in general allow smooth traffic in the building lobby.

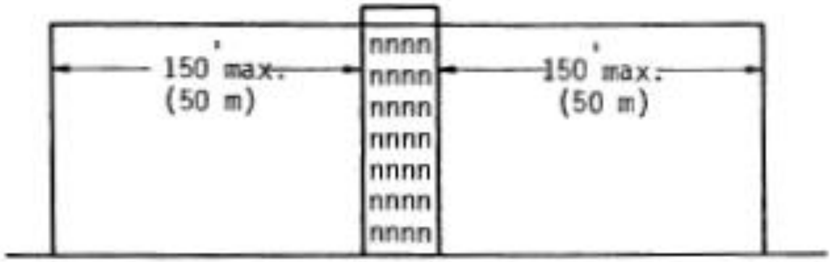


Figure 9.3: Distance from elevator core to farthest office not to exceed 150'.

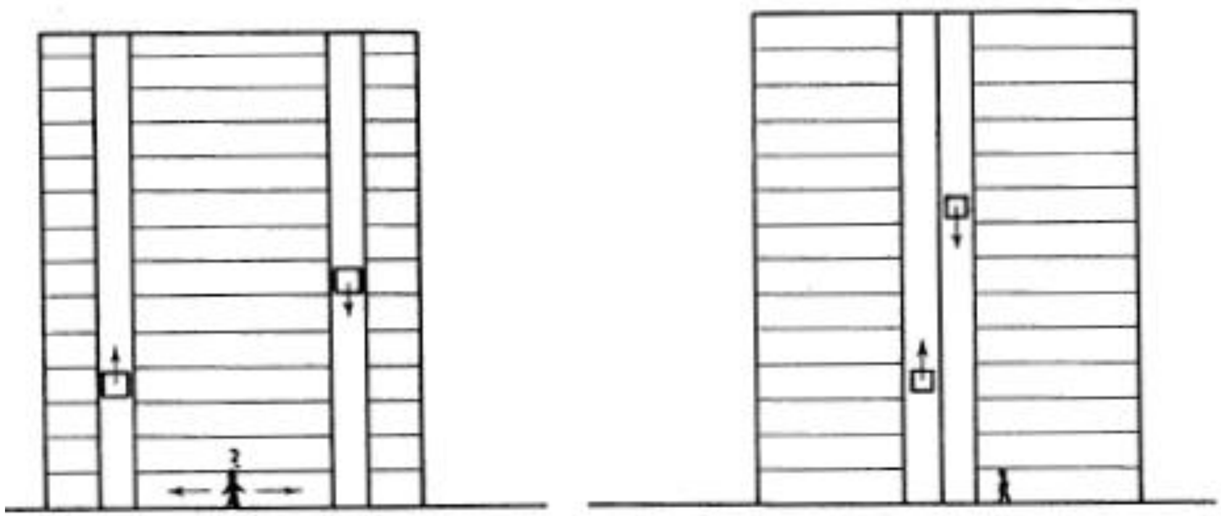


Figure 9.4: Cores should be arranged in a way to avoid passenger indiecision

- Elevator lobby on each floor should be the focal point from which corridors radiate for easy access to all rooms.
- All lobbies should be adequate in area for peak load gathering. Of course this area is determined by the number of people contributing to the peak load (15 - 20 min). Usually 4 ft^2 are allowed for each of the waiting passengers.

(4) Elevator cores should be in a clear and visible location especially for people entering the building.

(5) The indicator panel should be clear and visible.

(6) Within each core, the following conditions for arranging elevators should be observed.

(a) 2-car arrangement (Fig. 9.5)

Side by side is preferred.

(b) 3-car arrangement (Fig. 9.6a)

(c) 4-car arrangement (Fig. 9.6b)

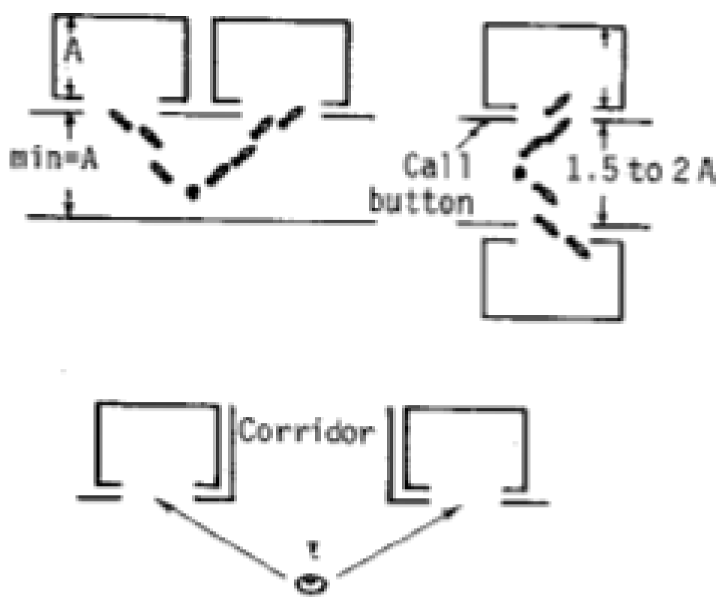


Figure 9.5: Two-car arrangements.

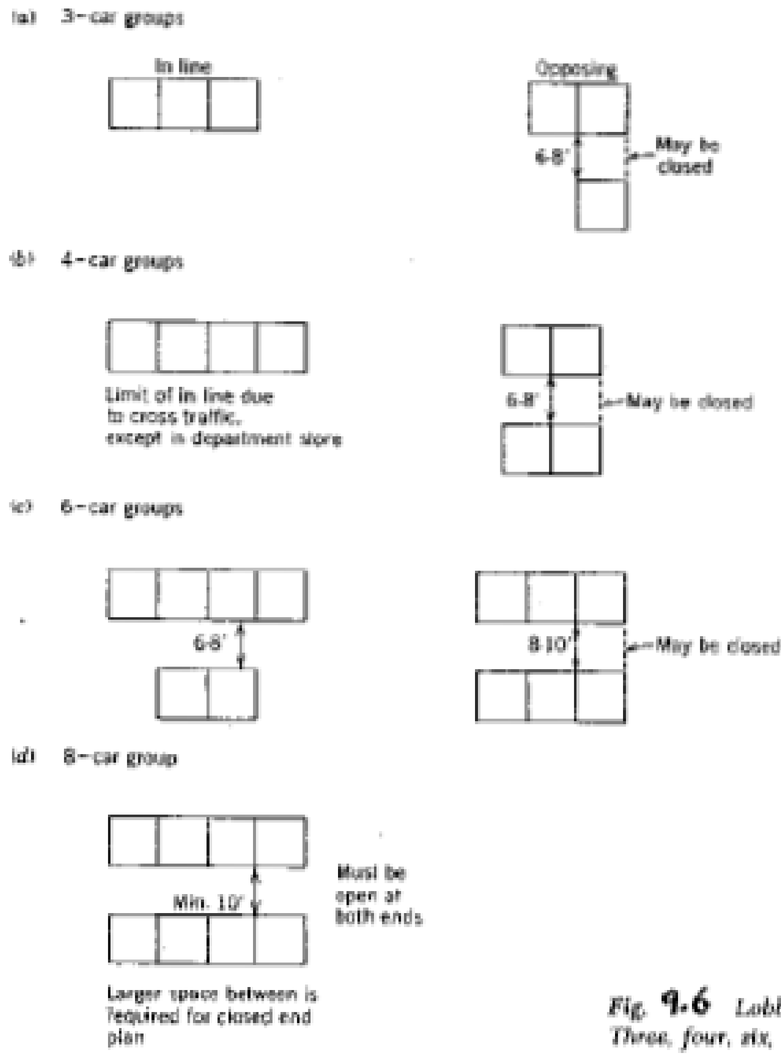


Fig. **9.6** *Lobby groupings for sin Three, four, six, and eight-car group*

9.8 Elevator Shaft, Pit and Penthouse

(a) Shaft

It is the vertical passage way for the car and counter weights. It has guide rails on its side walls as well as some mechanical and electrical control equipment.

Figure 9.6R gives rough elevator dimensional data which can be helpful in preliminary architectural design.

(b) Pit

It is the space at the bottom of the shaft where the car buffers (springs/dampers) are located.

(c) <u>Penthouse and secondary level floor</u>

The penthouse contains the elevator traction machine and control panels. The secondary level floor contains additional equipment such as the sheave.

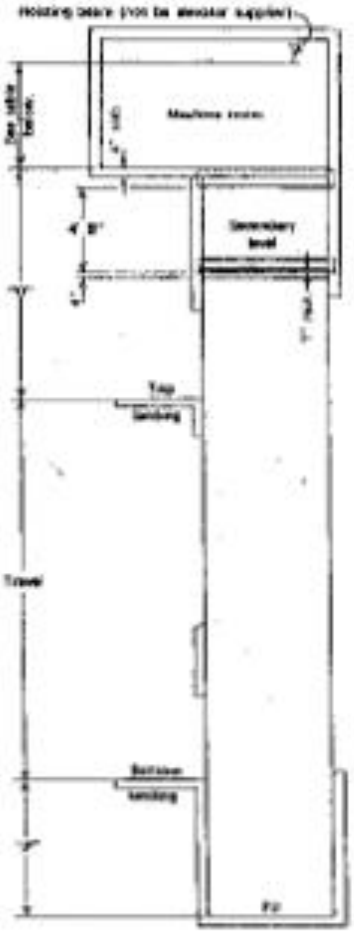
- o located above the shaft.
- o requires about 2 <u>stories</u> of additional height above the top of the elevator when it is standing at its top floor location.
- o floor area of the penthouse is about twice area of the shaft, while the area of the secondary level is the same as the area of the shaft.

1975 Edition

ELEVATOR ENGINEERING STANDARDS

Passenger Elevators,
Rated Speeds 500–700 fpm

Dimensions in tables meet the requirements of the ANSI-A17.1 Code for elevators.
Check local code for increased requirements.



Notes:

*** Min. Top of Machine Room Floor "O"**

Speed			Rated Load			
fpm	2000	2500	3000	3500	[illegible]	[illegible]
500	24'4"	24'4"	[illegible]	[illegible]	[illegible]	[illegible]
600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Min. Pit Depth "P"

Speed			Rated Load			
fpm	2000	2500	3000	3500	4000	[illegible]
500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

) min. pit depth

Clear Height of Machine Room
(Min. Height Under Hoisting Beam)

Rated		Rated Speeds	
Load	500	600	700
2000	[illegible]	[illegible]	[illegible]
2500	[illegible]	[illegible]	[illegible]
3000	[illegible]	[illegible]	[illegible]
3500	[illegible]	[illegible]	[illegible]
4000	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

) height of machine room

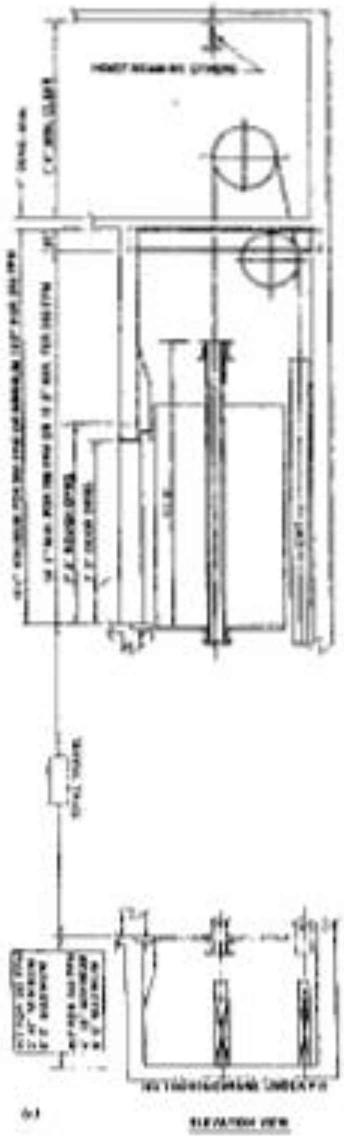


Fig. 96R Manufacturer's typical layout drawing. Shown are machine room (a), hoistway plan (b), and hoistway section (c), for one, two, or three 2500 lb, 100 to 350 fpm geared premanufactured elevator cars. Courtesy of Montgomery Elevator Co.

9.9 Structural Stresses

To design the main beams which support the penthouse floor and subfloor, one should have a very good estimate of the elevator loads. These loads are usually divided into:

(a) Static loads such as equipment weights, elevator weight and passenger weights.

(b) Dynamic loads which result from the rate of change of momentum of the moving masses (car, counter weight, etc...). When elevator is retarded to a stop, substantial dynamic forces result. These loads should be accounted for.

9.10 Elevator Selection

The main criteria for elevator selection are:

(a) Interval and average waiting time.

(b) Handling capacity.

(c) Travel time.

9.10.1 Definitions

(a) Interval, I

It is the average time between departure of cars.

(b) Average Lobby Time or Average Waiting Time, Tw

It is the average time spent by a passenger between arriving in the lobby and leaving in a car.

(c) Registration Time, Tr

It is the waiting time at an upper floor after registering a call.

(d) Round Trip Time, RT

It is the average time required for a car to make a round trip starting from the lower terminal and returning to it. This includes a statistically determined number of upper floor stops in one direction and an express return trip.

(e) Travel Time or Average Trip Time, AVTRP

It is the average time spent by passengers from the movement they arrive in the lobby to leaving the car at an upper floor.

(f) Handling Capacity, HC

It is an indication of the maximum number of passengers that can be handled in a given period. Usually this period is taken equal to 5 minutes; the handling capacity then is called the 5-min. handling capacity or simply HC. When HC is expressed as % of the building population, it is called the percent handling capacity, PHC.

(g) Zone

A zone is group of floors that are served by one elevator system.

9.10.2 Relation Between Interval and Waiting Time

Since the average time between the arrival of cars is I (interval) and passengers arrive randomly, it is expected that average waiting time to be about 0.5 I. However, tests showed that

$$\text{Average waiting time} \cong 0.6 \text{ I}.$$

Elevator service can be classified according to the waiting time during peak time as follows:

Excellent	waiting time	=	15 - 18 sec
Average (good)		=	22 sec
Border line		=	26 sec

Suggested Elevator Intervals are given in Table 9.1.

9.10.3 Handling-Capacity Relation

The Handling Capacity of an elevator system depends on:

1) The frequency or interval I

2) The capacity of the car p i.e. the number of passengers that a car is rated to accomodate. Note also that even at peak time, cars are not loaded completely but loaded to about 80% of their maximum capacity.

The 5-minute HC period is usually taken as standard.

$$HC = \frac{5 \text{ min.} \times 60 \text{ sec/min} \times \text{Passengers/car}}{\text{Interval (sec)}}$$

$$HC = \frac{300\ P}{I}$$

The individual car loading or passenger capacity is given in Table 9.2 for typical elevator cars.

A good system in a diversified building should have a 5 min. handling capacity of 12% of the building population. Table 9.3 below gives more details.

Table 9.1 *Suggested Elevator Intervals*

Facility	*Interval (in Seconds)*
Office Buildings	
Center city	25 to 30
Investment	30 to 40
Residential	
Prestige apartments	50 to 70
Middle-income apartments	60 to 80
Low-income apartments	80 to 120
Dormitories	60 to 80
Hotels—1st quality	40 to 60
Hotels—2nd quality	50 to 70

Table 9.2 *Car Passenger Capacity*

Elevator Capacity (Pounds)	*Maximum Passenger Capacity*	*Normal Passenger Load per Trip*
2000	12	10
2500	17	13
3000	20	16
3500	23	19
4000	28	22

*The number of passengers carried on a trip during peak conditions is approximately 80% of the car capacity.

Table 9.4 ***Population of Typical Buildings for Estimating Elevator and Escalator Requirements***

	Net Area
Office Buildings	Square foot per person
Diversified:	
Large lower floors	110 to 120[a]
Upper floors	120 to 145
Average use	130
Single purpose	120
Hotels	Persons per sleeping room
Normal use	1.3
Conventions	1.9
Hospitals	Visitors per bed[b]
General private	1.5
General public (large wards)	3 to 4
Apartment Houses	Persons per bedroom
High rental	1.5
Moderate rental housing	2.0
Low-cost housing	2.5 to 3.0

[a] Density may vary for different floors. Clerical and stenographic area may have a population density as high as 50 sq ft per person.

[b] If visiting hours are restricted, visitor population will determine elevator requirements. If visiting is not restricted to only a certain few hours, staff requirements may determine elevator design. Where traffic is heavy, a combination of passenger cars and larger "hospital" cars should be used to provide optimum service.

Table 9.3

Application	$(PHC)_{min.}$
Office building	13 to 15%
Residential	
Prestige	5 to 7
Other	6 to 8
Dormitories	10 to 11
Hotels, first quality	12 to 15
Hotels, second quality	10 to 12

9.10.4 Estimation of building population

The starting point in figuring the number and size of elevators is the number of users which is generally equal to the building population. The estimation of such population is quite difficult. It depends among other things on building use. Tables based on previous experience give the area allowed per person or some other equivalent parameter. Table 9.4 gives such data for a number of applications.

9.10.5 Travel Time or Average Trip Time AVTRP

It is defined as the sum of

(a) lobby waiting time

(b) travel time to the median floor

In Commercial Buildings

Trip time $<$ 1 min. is highly desirable

= 75 sec is acceptable

= 90 sec is annoying

= 120 sec is the limit of tolerance.

The average trip time is a function of number of local floors, speed of elevator, height between consecutive floors, car weight capacity and interval.

9.10.6 Round Trip Time RT

It is the time consumed by a car from door opening at the lower terminal to door opening at the same terminal at the end of a round trip to a median floor. Obviously RT depends on elevator speed, number of floors, floor to floor height and car weight capacity.

RT is composed of the time for each of

(a) Loading at the lobby.

(b) Door closing at the lobby.

(c) Accelerating from terminal.

(d) Decelerating at each stop.

(e) Passenger transfer at each stop.

(f) Door operation at each stop.

(g) Running time at rated speed between stops.

(h) Return express run from the last stop.

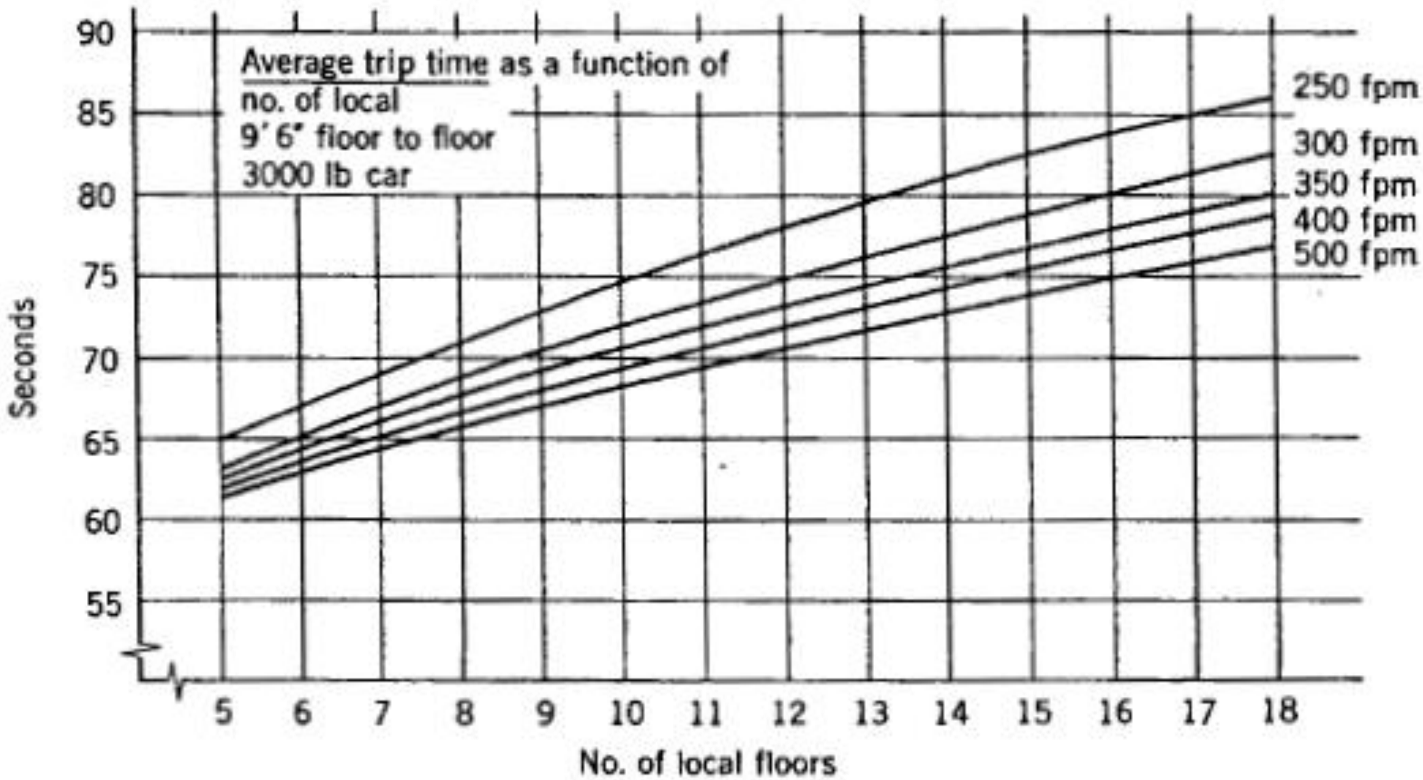
Charts given in Figs. 9.9 and 9.10 give RT variation with the number of floors and speed for a given car capacity and floor to floor height.

9.10.7 System Relationships

Here is a list of symbols used; most of them have been defined earlier.

p   Individual car passenger capacity = 80% of maximum during peak hours.

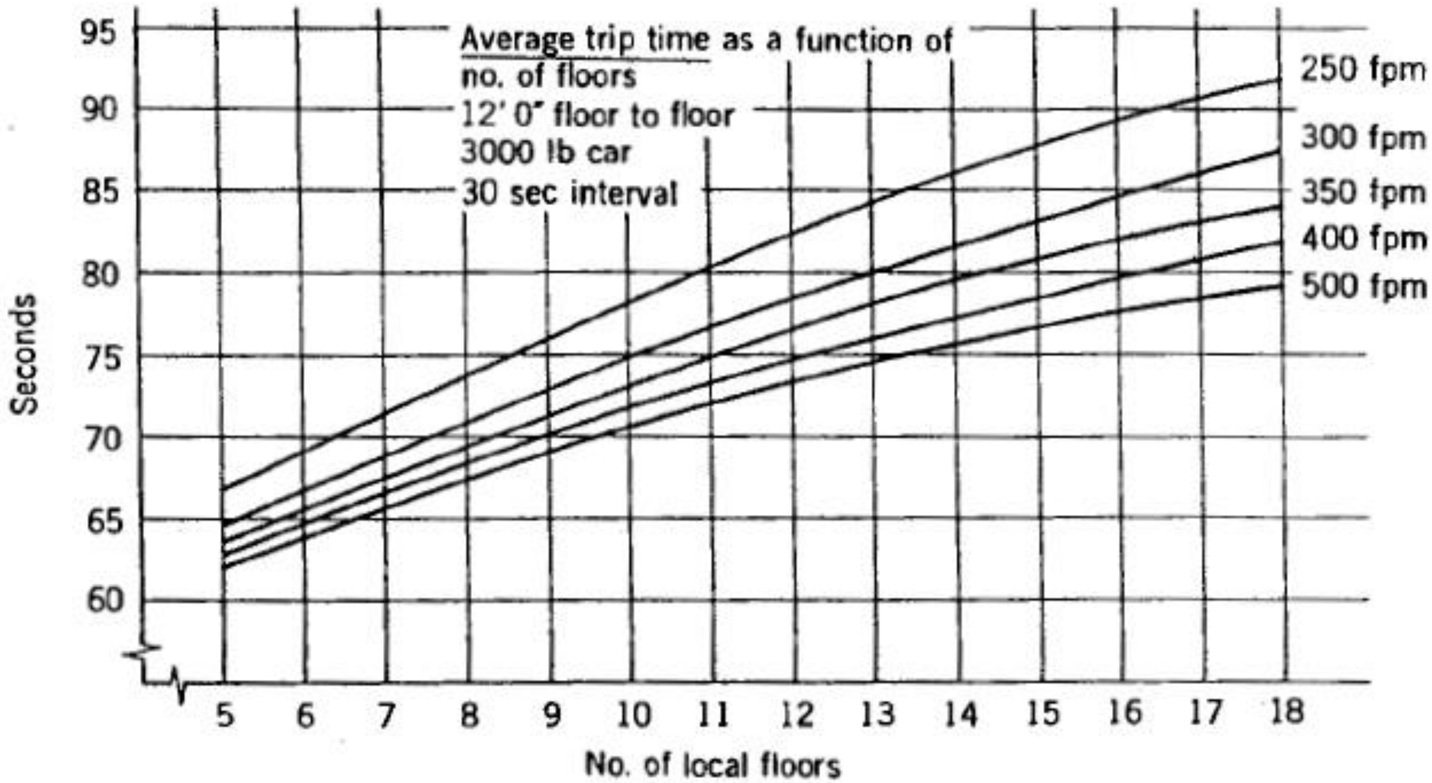
(b)



(c)

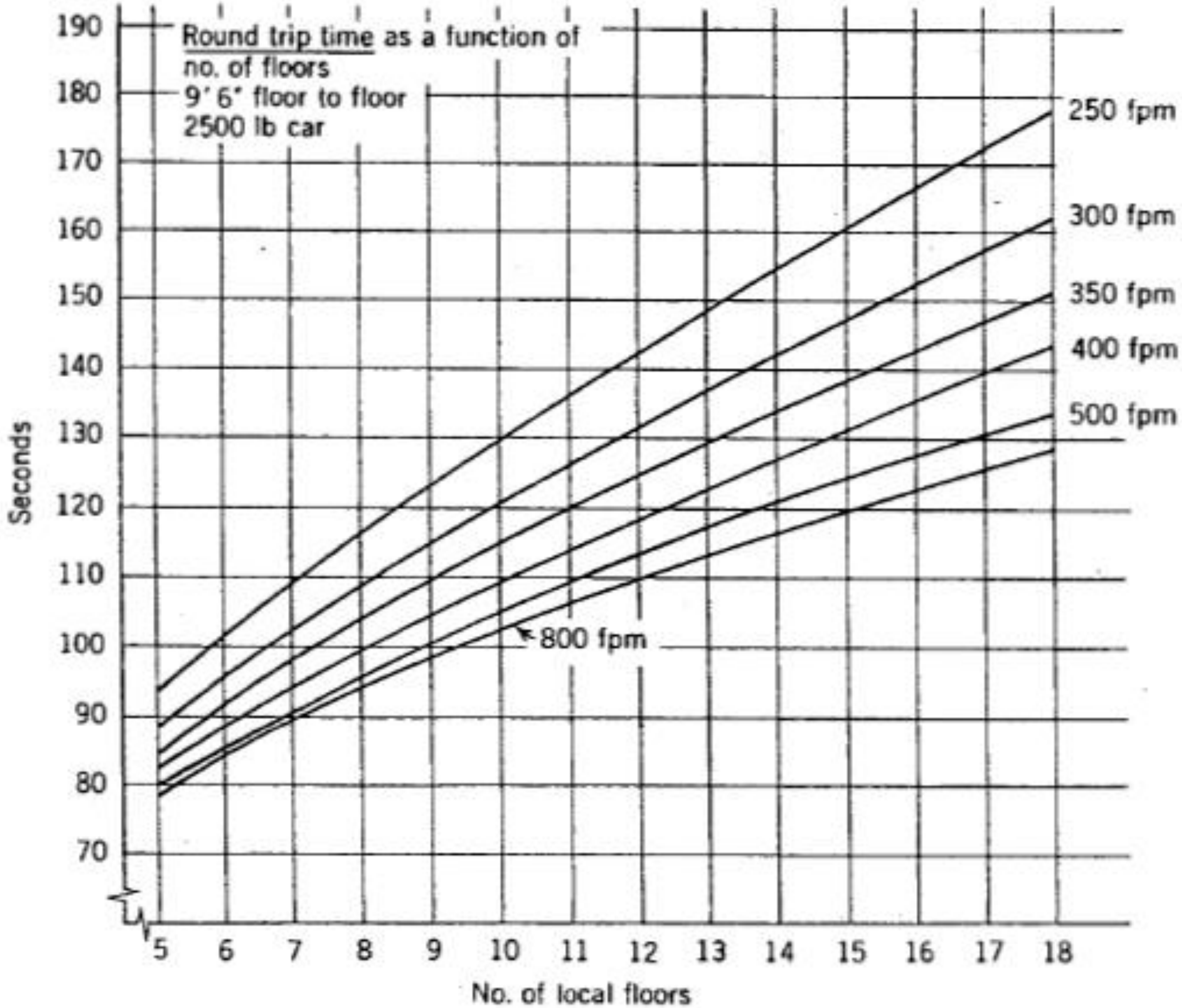
Fig. 9.7 *Plots of average trip time for various car speeds and capacities with 9 ft 6 in. floo*

(b)



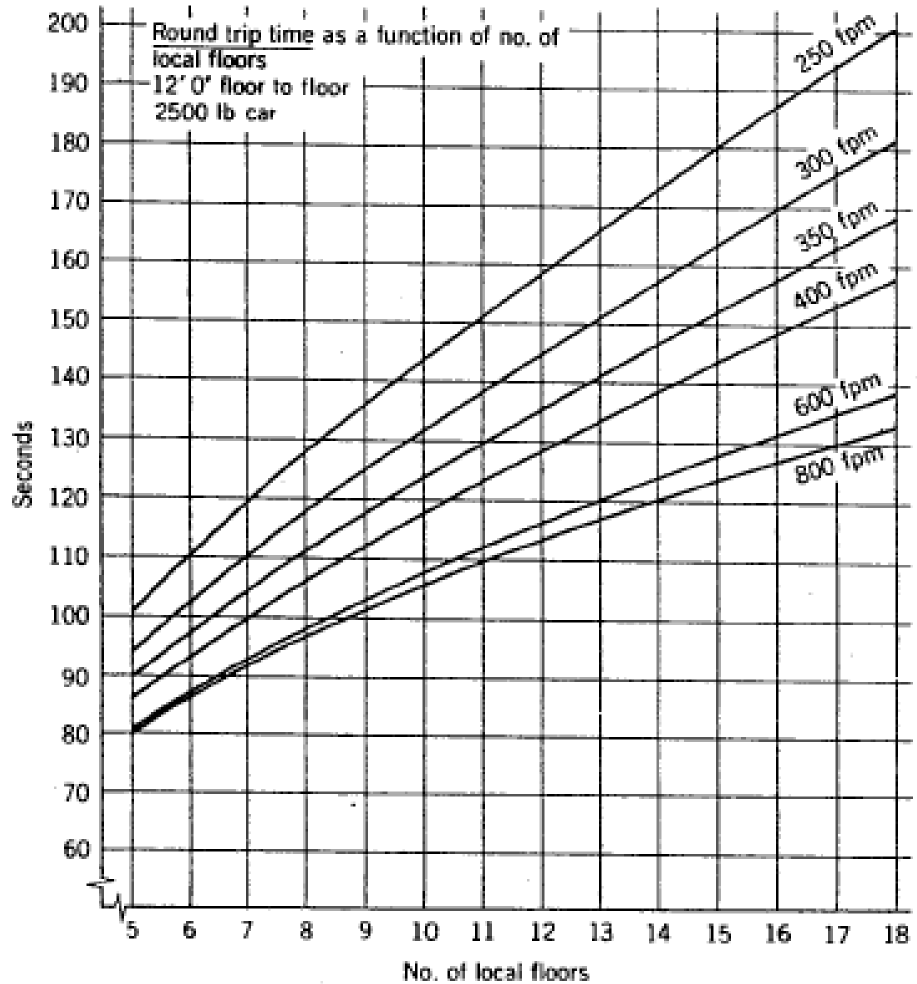
(c)

Fig. 9.8 *Plots of average trip time for various car speeds and capacities with 12 ft 0 in. floor heig*



(b)

Fig. 9.9 Plots of round-trip time for various car speeds and capacities with 9 ft 6 in. floor heig



(b)

Fig.9.10 RT variation for various car speeds and capacities with 12' floor height.

Table 9.5 *Elevator Equipment Recommendations*

Usage		*Car Capacity (Pounds)*	*Minimum Car Speed*[a] *(Feet per Minute)*	*Car Travel (Feet)*
Office buildings			350 to 400	0 to 125
	Small building	2500	500 to 600	126 to 225
	Medium building	3000	700	226 to 275
	Large building	3500	800	276 to 375
			1000	Above 375
Hotels		2500		
		3000	As above	As above
Hospitals			150	0 to 60
			200	61 to 100
		3500	250 to 300	101 to 125
		4000	350 to 400	126 to 175
			500 to 600	176 to 250
			700	Above 250
Apartment houses[b]			100	0 to 75
		2000	200	76 to 125
		2500	250 to 300	126 to 200
			350 to 400	Above 200
Retail stores			200	0 to 100
		3500	250 to 300	101 to 150
		4000	350 to 400	151 to 200
		5000	500	Above 200

[a]Geared equipment is used up to 400 fpm, gearless at higher speeds.

[b]FHA minimum requirements call for full-collective variable voltage control; minimum of two cars; and approximately 120 bedrooms per car, for all buildings exceeding seven stories in height.

h	5-min handling capacity of a single car.
N	No. of cars in a system.
HC	5-min. handling capacity of system.
RT	Round trip time, in seconds.
AVTRP	Average trip time, sec.
I	Interval
PHC	% of population to be moved in 5 min.

The important system relations are as follows:

$$HC = 300\ p/I \quad (1)$$

$$h = 300\ p/RT \quad (2)$$

$$I = RT/N \quad (3)$$

$$N = HC/h \quad (4)$$

The above relations are used to determine the number of elevators provided a car (passenger capacity, speed, weight) has been selected. A typical procedure is illustrated in Example in Section 9.11.

9.10.8 Car Selection

In general, it is trial and error procedure. The criterion is to give acceptable I. Table 9.5 can be used to make a reasonable initial guess for car selection. The car travel and building type and size are the parameters used in this table to determine the initial guess of car.

9.11 An Example for System Design

A procedure for the determination of the elevator system is illustrated through the following example.

Example 1

An Office Building for diversified use is located in the downtown area. It has 14 rentable floors above lobby. The area of each floor is 12,000 ft^2 net and the floor to floor height is 12 ft. Determine a workable elevator system.

Procedure

(1) The minimum (PHC) for this application as suggested in Table 9.3 is 13%.

$$(PHC)_{min} = 13\%$$

PHC % of population to be moved in 5 min.

Table 9.3

Application	$(PHC)_{min.}$
Office building.	13 to 15%
Residential	
Prestige	5 to 7
Other	6 to 8
Dormitories	10 to 11
Hotels, first quality	12 to 15
Hotels, second quality	10 to 12

(2) Table 9.1 suggests that I_{max} = 30 sec.

(3) The average population density is estimated to be such that 130 ft^2 are allowed per person. (Table 9.4).

Therefore,

$$\text{Building population} = \frac{14 \times 12{,}000}{130} = 1292 \text{ persons}$$

$$HC = 0.13 \times 1292 = 168 \text{ persons}$$

$$\text{Building rise} = 14 \text{ floors} \times 12 = 168 \text{ ft}$$

Table 9.1 *Suggested Elevator Intervals*

Facility	*Interval (in Seco*
Office Buildings	
Center city	25 to 30
Investment	30 to 40
Residential	
Prestige apartments	50 to 70
Middle-income apartments	60 to 80
Low-income apartments	80 to 120
Dormitories	60 to 80
Hotels—1st quality	40 to 60
Hotels—2nd quality	50 to 70

Table 9.4 *Population of Typical Buildings for Estimating Elevator and Escalator Requirements*

	Net Area
Office Buildings	Square foot per person
Diversified:	
Large lower floors	110 to 120*
Upper floors	120 to 145
Average use	130
Single purpose	120

Initial Trial

(3) Based on the recommendations in Table 9.5, the following car is chosen

Car weight = 3000 lbs

No. of passengers per car = 16 (Table 9.2)

Speed = 500 fm

ations

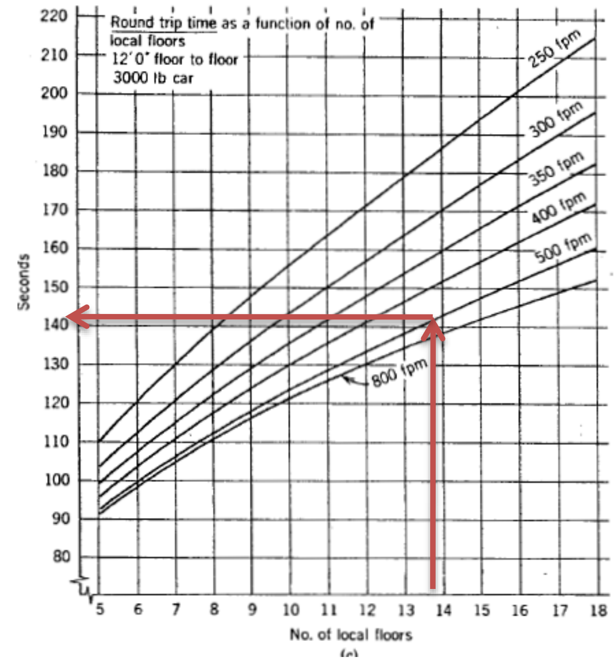
Car Capacity (Pounds)	*Minimum Car Speed* (Feet per Minute)*	*Car Travel (Feet)*
	350 to 400	0 to 125
2500	500 to 600	126 to 225
3000	700	226 to 275
3500	800	276 to 375
	1000	Above 375

(4) Using figure 9.10c, the round trip time is obtained.

$$RT = 143 \text{ sec}$$

while the average trip time is obtained from Fig.9.8c.

$$AVTRP = 76 \text{ sec}$$



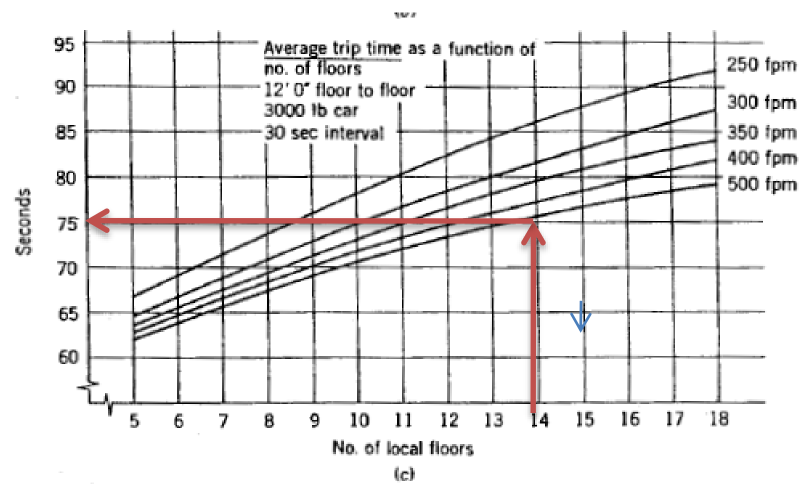
(5) Single car 5-min handling capacity

$$h = \frac{300\ P}{RT} = \frac{300\ (16)}{143}$$

$$= 33.5 \text{ persons}$$

(6) No. of cars,

$$N = \frac{168}{33.5} \simeq 5.0 \text{ cars}$$



(7) The interval is given by

$$I = \frac{RT}{N} = \frac{143}{5} = 28.3 \text{ sec.}$$

Table 9.1 suggests an interval of 30 sec. Therefore the above result of 28.3 sec appears excellent.

Second Trial

Let us now investigate the possibility of reducing the number of cars by using faster cars. The car chosen is:

weight	3000 lbs
p	16 persons
speed	600 fpm

RT under these conditions is 137 sec.

$$h = \frac{300\ P}{RT} = \frac{300 \times 16}{137} = 35 \text{ persons}$$

$$N = \frac{168}{35} = 4.8 \rightarrow \text{say } 5$$

$$I = \frac{137}{5} \rightarrow 27.4 \text{ sec.}$$

$$\text{Actual PHC} = \left(\frac{5}{4.8}\right) \times 13\% = 13.5\%$$

This solution is not better than the initial choice, moreover it costs more because of faster cars.

Other Trials

(a) Larger cars : 3500 lbs cars

At 500 fpm

RT = 155 sec, h = 36.8

N = 4.56 → 5, no advantage

At 600 fpm

RT = 152 sec, h = 37.5

N = 4.48 → 4

I = 42 sec., excessive

Third Trial

Now we will try slower cars to reduce cost. Let us try a 3000 lbs car with a speed of 400 fpm

$$RT = 152 \text{ sec}$$

$$AVTRP = 77 \text{ sec.}$$

$$h = \frac{300\ p}{RT} = \frac{300 \times 16}{152} = 31.6$$

$$N = \frac{168}{31.6} = 5.3 \rightarrow \text{use } 5$$

$$I = \frac{RT}{N} = \frac{152}{5} = 30.4$$

$$\text{Actual PHC} = \frac{5}{5.3}(13) \times 100 = 12.26\%$$

Actual PHC is slightly below the minimum for this applicaton. Therefore among the 3000 lbs class of cars, the acceptable solution is 5 cars at 500 fpm.

Recommendations for the choice of elevators

for residential buildings based on the diagrams produced by the FEM and taking account of the building bylaws of the individual German states (fire-service elevators are not taken into account)

Capacity requirements

①	1 × 400 kg		0.63 m/s
②	1 × 400 kg		1.0 m/s
③	1 × 630 kg		1.0 m/s
④	1 × 1000 kg		1.0 m/s
⑤	1 × 400	+ 1 × 1000 kg	1.0 m/s
⑥	1 × 630	+ 1 × 1000 kg	1.0 m/s
⑦	2 × 1000 kg		1.0 m/s
⑧	1 × 630	+ 1 × 1000 kg	1.6 m/s
⑨	2 × 1000 kg		1.6 m/s
⑩	2 × 630	+ 1 × 1000 kg	1.6 m/s
⑪	3 × 1000 kg		1.6 m/s
⑫	2 × 1000 kg		2.5 m/s
⑬	3 × 1000 kg		2.5 m/s