Abstract

Many hospital patients are immobile. Therefore, evacuation assessment regulations for hospital buildings should be more demanding than for other buildings. The Taiwan Building Code has established some limitations on population density of some divisions in medical facilities. However, evacuation assessment is still difficult due to the lack of information about the speeds with which different people can move or be moved. People’s speeds and population density has been investigated in this study. The results show average speeds for four types of people are 1.28 m/sec for people with no restricted movement, 0.55 m/sec for those moving with restriction, 0.82 m/sec for those requiring the most assistance, and 0 m/sec for those can’t leaving from hospital. Population densities in administration and policlinic zones are lower than the standard in the Taiwan Building Code and in neonatology rooms, they are higher.

Keywords: evacuation assessments; medical facilities; population density; people’s movement abilities; evacuation plans

Introduction

In recent years, hospitals in Taiwan have been growing in larger numbers and scales. Having accommodated many people with impaired abilities, the hospitals are in greater danger and suffer heavier casualties than other buildings in case they are on fire. Therefore, evacuation assessment regulations for hospital buildings are more demanding than for other buildings. So far, the Taiwan Building Code has established some limitations on population densities of some divisions in hospital buildings, while such zones as lobbies and emergency rooms are out of consideration. In addition, the information about people’s speeds in hospitals is unavailable. Some related studies are also lacking such background information. For the reasons given above, this paper is intended to investigate population density and people’s speeds in hospitals.

Research Purposes

The purposes of this paper are as follows:
1. Observing and recording people’s speeds in hospitals.
2. Observing and recording the population density of different divisions in hospitals.
3. Comparing the study results of population density with the standards in the Taiwan Building Code. The results of comparison can provide Taiwan hospital buildings with bases of needed time for evacuation in establishing disaster prevention plans.
4. Providing suggestions to limitations of population density in the Taiwan Building Code on such zones as lobbies and emergency rooms.

Research Objects

The following are the hospitals chosen for investigation:
1. Regional hospitals selected by Taiwan Bureau of National Health Insurance.
2. Taiwan is divided in four regions (north, middle, south and east) according to administrative divisions and different geographical features shown in Taiwan National Land Development Planning. Two to Three regional hospitals in each region are served as objects of this research.

The main users in hospitals are patients and medical personnel. In this paper, observed objects include patients, the medical personnel, the administrative personnel, visitors and the general public.

Research Methods

The research methods are observation and interview. Since hospitals are open to the public, it is impossible to know the exact distribution of people there. Thus, observation is adopted as the main research method.

Moreover, general people are restrained from entering some special divisions (ex. the operational zones) in hospitals. In this case, information is got by interviewing the medical personnel and administrative personnel.

Points of investigation are summarized below.
1. People’s speeds
2. Population density of the following zones
(1) Lobbies
(2) Administration Division
(3) Medical Treatment Departments
   A. Policlinic Zones
   B. Screen and Remedy Rooms
   C. Sickroom Zones
   D. Emergency Rooms
   E. Special Medical Treatment Departments
      (a) Operational Zones
      (b) Intensive Case Unit Center
      (c) Delivery Rooms
      (d) Neonatology Rooms

Investigate Programs
Throughout observation and personal interview, this study attempted to take insight into (1) population density at rush hours and the others, (2) People' speeds in hospital buildings, and establish the database for the future evacuation assessment plans.

Nine regional medical facilities in Taiwan are chosen to study. Fig.1 shows all the location of investigated hospitals. Table 1 gives the total floor area and sickbed numbers of these hospitals. This study was started in December 1997, and ended in April 1998. Each hospital had been surveyed for one week, including five weekdays and a weekend. And observation was carried out in the morning (AM8:30- AM12:00), afternoon (PM1:00- PM05:30), and evening (PM06:00- PM10:00) one day.

Table 1. Scope of Regional Hospitals to Study

| Region | Hospital | Total Floor Area (m²) | No. of Sickbeds |
|--------|----------|-----------------------|----------------|
| North  | A        | 40739                 | 563            |
|        | B        | 66847                 | 842            |
|        | C        | 24483                 | 591            |
| Middle | D        | 11636                 | 252            |
|        | E        | 11222                 | 81             |
| South  | F        | 23652                 | 768            |
|        | G        | 17126                 | 403            |
| East   | H        | 19292                 | 300            |
|        | I        | 60088                 | 713            |

Note: There are more than one building in hospitals D and E, and the survey was made only in the main building of each hospital.

As shown in Table 2, people in hospitals were classified into four types on the basis of their movement patterns and abilities. As to get the speeds in horizontal movement, 396 cases (Type I: 114, Type II: 138, Type III: 144, and the speed of type IV is set to be zero) were observed and analyzed in this study.

Table 2. People’ Movement Patterns and Abilities in Hospitals

| Type | Movement Abilities | Assistance | Elucidation | No. of Cases |
|------|--------------------|------------|-------------|--------------|
| I    | Able to move       | -          | Those who can move | 114          |
| II   | Moveable but with restriction | person, clysis, wheelchair, crutch, walk-aid, hand rail, etc. | 1) Those who move with support tools. 2) Those that not only use assistant tools but also need someone help, ex: old men and babies. 3) Those who may not need assistant but move slowly, ex: defective vision and disturbance of intelligence | 138          |
| III  | Moveable with great assistance | person and clysis, person and wheelchair, person and crutch, person and walk-aid, person and stretcher, person and inspirator, etc. | Those who cannot use assistant tools without others' help. | 144          |
| IV   | Unable to move     | -          | Those who can't move due to serious sickness | -            |

Investigate results
1. People’ Evacuation Abilities
   Speed of Type I has changed from 0.78 m/sec to 1.83 m/sec, and the average speed is marked as 1.28 m/sec. Speed of Type II has varied from 0.33 m/sec to 1.29 m/sec, and the average is 0.55 m/sec. Speed of Type III has ranged from 0.32 m/sec to 2.07 m/sec, and the average speed is marked as 0.82 m/sec. Type IV are incapable of leaving from hospitals so that their moving speed was excluded in this survey. And the standard deviation for 95% confidence is noted as 0.2360 for Type I speed, 0.4610 for Type II speed, and 0.4122 for Types 3 speed.

2. Population Density at Each Zone
   (1) Lobbies
   Population density in lobbies has changed from 0.0129 person /m² to 0.0963 person /m². The average population density is 0.0561 person /m². As shown in Fig.2, and the
sample standard deviation of 95% confidence is 0.0479. Population density of medical personnel in lobbies has changed from 0.0031 person /m² to 0.3030 person /m². And the sample standard deviation of 95% confidence is 0.0164. By contrast, population density of patients and their visitors in lobbies has changed from 0.0098person /m² to 0.0683 person /m². And the sample standard deviation of 95% confidence for Type I, II, III, VI users in lobbies are 0.0359, 0.0049, 0.0011, and 0.0002 respectively.

(2) Administrative Division
Population density in administrative areas has changed from 0.0377 person /m² to 0.1324 person /m². The average population density is 0.0699 person /m². As shown in Fig.3, and the sample standard deviation of 95% confidence is 0.0308.

(3) Medical Treatment Departments

A. Polyclinic Zones
Population density of medical personnel in polyclinic zones has changed from 0.0147 to 0.0299person /m². While the population density of the other users is ranged from 0.0175 to 0.1173 person /m², and the average are 0.0829 person /m². As shown in Fig.4, the sample standard deviations of 95% confidence for the above-described parameters are 0.0636, 0.0223, and 0.0831 respectively.

B. Screen and Remedy Rooms
Population density of medical personnel in screen and remedy rooms has changed from 0.0090 to 0.0197 person /m². And population density of the other users has ranged from 0.0025 to 0.0237 person /m². Total population density has varied from 0.0104 to 0.0434 persom/m². and the average is 0.0245 person /m². As shown in Fig. 5, the sample standard deviations of 95% confidence for the medical personnel, the other users, and all the people in screen and remedy rooms are 0.0085, 0.0049, and 0.0129 respectively.

C. Sickroom Zones
(a) Weekdays
As shown in Fig.6, population density of medical personnel has changed from 0.0040 to 0.0119 person / m². Population density of patients has ranged from 0.0254 to 0.0279 person /m². And the population density
of patients’ relatives has varied from 0.0233 to 0.0279 person/m². Total population density has a range changing from 0.0571 to 0.0649 person/m², and the average is 0.0598 person/m². The sample standard deviation of 95% confidence is 0.0036.

(b) **Weekend**

Referring to Fig.6, population density of medical personnel has changed from 0.0023 to 0.0084 person/m². Population density of patients has ranged from 0.0235 to 0.0257 person/m². And population density of patients’ relatives and visitors has varied from 0.0222 to 0.0239 person/m². Total population density has a range changing from 0.0489 to 0.0580 person/m², and the average is 0.0527 person/m². The sample standard deviation of 95% confidence is 0.0039.

**D. Emergency Rooms**

Population density of medical personnel in policlinic zones has changed from 0.0152 to 0.0266 person/m². And while population density of the other users has ranged from 0.0377 to 0.0524 person/m². Total population density has varied from 0.0572 to 0.0790 person/m² and the average is 0.0650 person/m². As shown in Fig. 7, the sample standard deviations of 95% confidence are 0.0197, 0.0086, 0.0051, 0.0036, 0.0292, 0.0120 and 0.0368 respectively for Type I, II, III, IV, total of people, personnel and all of people.

**E. Special Medical Treatment Departments**

(a) **Operational Zones**

The maximum density of patients (sickbeds) is 0.0088 person/m² (bed/m²). The maximum density of medicine personnel is 0.0568 person/m², and the minimum density of medicine personnel is 0.0046 person/m².
maximum population density is 0.0656 person \( / \text{m}^2 \). As shown in Fig. 8, the sample standard deviations of 95\% for these four parameters are 0.0027, 0.0173, 0.0048 and 0.0270 respectively.

(b) Intensive Case Unit Center

The maximum density of patients (sickbeds) is 0.0365 person \( / \text{m}^2 \) (bed/m\(^2\)). The sickbeds be used percentage is 78\%, therefore the average density of patients is 0.0284 person \( / \text{m}^2 \). The maximum density of medicine personnel is 0.0243 person (bed)/m\(^2\), and the minimum density of medicine personnel is 0.0143 person/m\(^2\). As illustrated in Fig. 8, the maximum population density is 0.0608 person \( / \text{m}^2 \). The sample standard deviations of 95\% for these five parameters are 0.0119, 0.0111, 0.0118, 0.0083 and 0.0114 respectively.

(c) Deliver Rooms

The maximum density of babies (sickbeds) is 0.2154 person \( / \text{m}^2 \); the average density of patients is 0.0715 person \( / \text{m}^2 \). The maximum density of medicine personnel is 0.0307 person \( / \text{m}^2 \), and the minimum density of medicine personnel is 0.0194 person/m\(^2\). The maximum population density is 0.2461 person/m\(^2\). As shown in Fig. 8, the sample standard deviations of 95\% for these five parameters are 0.0119, 0.0111, 0.0118, 0.0083 and 0.0114 respectively.

(d) Neonatology Rooms

The maximum density of babies (sickbeds) is 0.2154 person \( / \text{m}^2 \); the average density of patients is 0.0715 person \( / \text{m}^2 \). The maximum density of medicine personnel is 0.0307 person \( / \text{m}^2 \), and the minimum density of medicine personnel is 0.0194 person/m\(^2\). The maximum population density is 0.2461 person/m\(^2\). As shown in Fig. 8, the sample standard deviations of 95\% for these five parameters are 0.0119, 0.0111, 0.0118, 0.0083 and 0.0114 respectively.
parameters are 0.1442, 0.0859, 0.0148, 0.0106 and 0.0658 respectively.

It also deserves some attention that population density of babies is different from hospitals to hospitals. The maximum is 0.2730 person/m², and the minimum is 0.0071 person/m². The ratio of the maximum to the minimum is about 38.

**Conclusion**
The investigation of people’s speeds and population density in hospitals can provide Taiwan hospital buildings with bases of needed time for evacuation in establishing disaster prevention plans.

1. According to the investigation of nine regional medical facilities in Taiwan, the following results are obtained: People’s average speeds (of each movement type) are shown as follows:
   - Type I (moving with no restriction): 1.28 m/sec
   - Type II (moving with restriction): 0.55 m/sec
   - Type III (requiring the most assistance): 0.82 m/sec

2. As shown in table 3, investigating the results about max and min of population density in each zone.

3. Table 4 shows the comparison of study results of population density and standards in the Taiwan Building Code. Population densities in administrative and policlinic zones are lower than the standard in the Taiwan Building Code. But in neonatology rooms, they are higher.

4. The maximum of population density in sickroom zones is observed on weekdays. A higher population density of patients’ visitors in sickroom zones appears in the evening on weekdays and in the morning on weekends.

The population density in public zones remains at a high level at daytime on weekdays.

**Suggestions**
Design and construction practitioners all over the world are struggling to come to terms with increasingly stringent regulations about accommodating people with impaired perception, mobility or understanding.

The following results offer informative references:
1. Based on the study results, population densities in neonatology rooms are higher than the standard in the Taiwan Building Code (0.0800).

| The Name of Zones                  | Total density of all of people |
|-----------------------------------|-------------------------------|
|                                    | Max   | Min   |
| Lobbies                           | 0.0963| 0.0129|
| Administration Division           | 0.1324| 0.0377|

| Medical Treatment Departments     |                               |
|-----------------------------------|-------------------------------|
|                                    | Total density of all of people |
|                                    | Max   | Min   |
| Policlinic Zones                  | 0.1472| 0.0365|
| Screen and Remedy Rooms           | 0.0434| 0.0104|
| Sickroom Zones                    | 0.0649| 0.0571|
|                                    | Weekdays                      |
|                                    | 0.0580| 0.0489|
|                                    | Weekend                        |
| Emergency Rooms                   | 0.0790| 0.0572|

| Special Medical Treatment Departments | Total density of all of people |
|---------------------------------------|-------------------------------|
|                                      | Max   | Min   |
| Operational Zones                    | 0.0656| 0.0134|
| Intensive Case Unit Center           | 0.0608| 0.0508|
| Delivery Rooms                       | 0.0585| 0.0423|
| Neonatology Rooms                   | 0.2461| 0.2339|
Table 4. Comparison of study results of population density and standards in the Taiwan Building Code for Regional Medical Facilities in Taiwan

| The Name of Zones | Taiwan Building Code (version of Jan. 9, 2003) | Study Results (Max) |
|-------------------|-----------------------------------------------|---------------------|
| Lobbies           | Unavailable                                    | 0.0963              |
| Medical Treatment Departments |
| Policlinic Zones  | 0.3000                                         | 0.1472              |
| Screen and Remedy Rooms | Unavailable                     | 0.0434              |
| Sickroom Zones    | number of sickbed*2.0                     | 0.0649 (Weekdays)   |
| Emergency Rooms   | Unavailable                                    | 0.0580 (Weekends)   |
| Special Medical Treatment Departments |
| Operational Zones | 0.0800                                         | 0.0656              |
| Intensive Case Unit Center |                     | 0.0608              |
| Delivery Rooms    |                                               | 0.0585              |
| Neonatology Rooms |                                               | 0.2461              |

Population density (person/m²) in administration division
Study result (0.1324) < Standard in the Taiwan Building Code (0.3000)

Population density (person/m²) in policlinic zones
Study result (0.1472) < Standard in the Taiwan Building Code (0.3000)

Population density (person/m²) in neonatology rooms
Study result (0.2461) > Standard in the Taiwan Building Code (0.0800)

In that case, the standard in Taiwan Building Code (0.0800) is suggested to be raised to a higher one for answering practical situations.

2. Population densities of lobbies and emergency rooms in hospitals are investigated in this paper. The statistics are suggested to be adopted by the Taiwan Building Code.

Follow-up Study
The higher population density is, the lower people’s speeds might become. Since the relationship between population densities and people’s speeds is still unknown, it can serve as a follow-up study.

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