EVACUATION CHALLENGES AND DESIGN CONSIDERATIONS FOR INWARD OPENING DOORS IN FIRE EMERGENCIES

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INTRODUCTION AND BACKGROUND

Inward opening doors have historically been associated with challenges in fire evacuation scenarios, particularly in situations involving high occupant densities. While outward opening doors are often favoured for egress due to their presumed efficiency, many existing buildings, especially those of cultural and historical significance, retain inward opening doors due to architectural and aesthetic considerations.

This paper addresses a critical gap in understanding the evacuation dynamics associated with inward opening doors. By exploring factors such as door mechanisms, spatial configurations, and occupant behaviour, the research aims to inform both safety regulators and design practitioners, offering actionable insights for new constructions and the preservation of heritage buildings.

Complete results and data are presented in report by Forssberg et al. [1].

SCOPE AND OBJECTIVES

This research seeks to enhance the understanding of evacuation processes involving inward opening doors by investigating their impact on occupant flow and safety. The primary focus is on identifying design parameters that influence the feasibility of egress through inward opening doors, including door fittings, corridor presence, and walking distance to exits.

The study extends its scope to address both practical challenges in retrofitting heritage buildings and the implications for new building designs. By aligning these insights with performance-based safety standards, the research aims to contribute to more robust evacuation strategies and open up for adjustments of restrictive building codes.

METHODOLOGY

The research methodology combines a comprehensive literature review with empirical evacuation experiments. The literature review examined building codes from various countries, historical fire incidents, and existing research on evacuation dynamics.

The experiments comprised 33 evacuation scenarios, varying parameters including door swing direction, occupant density, and the presence of a corridor in front of the egress door. Data was collected using multiple video cameras to analyse group formations, human interaction, and overall evacuation efficiency. Scenarios were designed to replicate both typical and high-stress evacuation conditions, offering a nuanced understanding of the factors influencing door performance.

LITERATURE REVIEW

Movement studies

Extensive research has historically been conducted on how people move during evacuations, focusing on walking speeds and flow through different environments such as doorways, stairs, and flat surfaces [2-8]. Some studies include the effects of obstacles like bollards, which in certain situations actually can increase the flow of people [9-10], but there is also research stating the opposite [8].

When people move in groups, they naturally adapt to optimize space and efficiency. Instead of forming straight lines, individuals stagger their positions to avoid being hindered by the person ahead [10]. In corridor-like settings, a distinct group shape with a front tip and a rear tail of people with low occupant density and a body of higher occupant density in the middle forms [3], see figure 1. It is therefore conceivable that the first person to reach an inward opening door, in this set up, will theoretically have the opportunity to open the door at the initial stage, without obstructive interference from other people in the group.

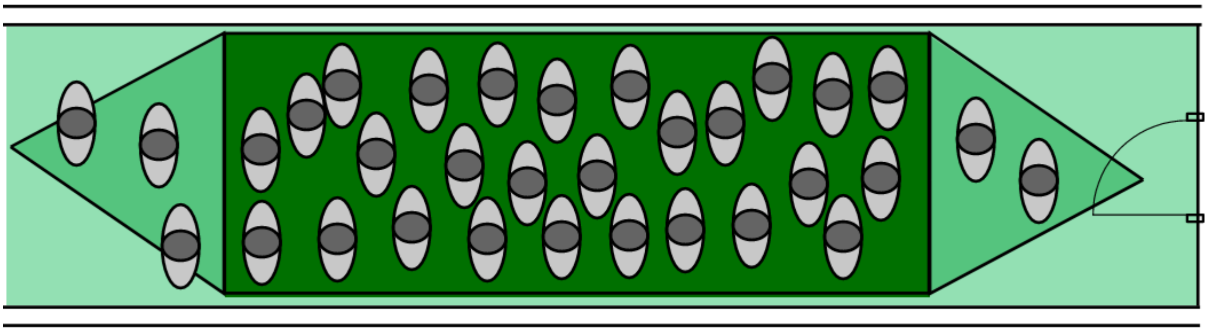

Figure 1. Distribution of people when moving in a group.

Two master's theses have been conducted at Lund University on evacuation through inward opening doors [12-13]. In these studies, evacuation experiments were conducted with 50-60 persons through inward opening doors. The studies concludes that inward-opening doors do not inherently hinder evacuation, even for groups of 50 or more people. The main factor influencing congestion and door usability is deemed to be occupant density, not the total number of evacuees.

Building regulations

Many countries' building codes allow the use of inward opening doors in the escape routes. However, it may only be allowed within some types of premises or with a limited number of people being expected to pass through such a door. Studied building regulations of some countries are presented in table 1 below.

Table 1. Inward opening doors in building regulations.

Country and building code	**Acceptance of inward opening doors**
Sweden, BFS 2024:7 [14]	For doors serving up to 30 persons.
Norway, TEK17 [15]	For a fire compartment holding up to 10 persons.
Denmark, BR18 [16]	For doors serving up to 150 persons.
USA, NFPA 101 [17]	For a room holding up to 50 persons.
England, BS 9999:2017 [18]	For doors serving up to 60 persons.
Australia, NCC [19]	For premises with a maximum floor area of 200 m^2

The wide-ranging acceptance of evacuation through inward opening doors indicate that the scientific background of building codes is quite scarce, and that the regulations appear to be based more on historical events and ingrained cultural traditions.

Accident investigations

A number of serious fire incidents involving large groups of people have been analyzed to determine whether inward-opening doors played a significant role in the outcomes. In total, 20 fire cases were examined. Of these, inward opening doors were highlighted to have played a crucial role in the outcome for four of the incidents [20-23].

The cases examined span a range of building types, with the earliest incident dating back to 1822. It is important to note that the quality and detail of the investigation reports vary significantly. While not all cases explicitly mention inward-swinging doors, their absence from the reports does not necessarily mean they were not present, as the direction of door openings is documented in only a few instances. Furthermore, even in cases where doors are known to have opened inward, it is not always clear whether this detail had any impact on the outcome of the fire. In some reports, the lack of clarity raises the possibility that the doors may have been locked, regardless of their swing direction.

In cases involving inward-opening doors, the fire often spread rapidly throughout the building, resulting in a very limited timeframe for evacuation. In other instances, it cannot be ruled out that the doors may have been locked. Consequently, the existing literature does not provide conclusive evidence that the direction in which escape doors open, whether inward or outward, poses a significant problem from a general standpoint.

Impact on fire development

As stated above, rapid fire development may influence the risk of using inward opening doors for evacuation purposes. A crucial factor to consider is whether the door can even be opened at all during a fire. Hostikka and Janardhan[24] conducted a study involving both practical experiments and computer simulations concerning pressure build-up during a fire in a residential apartment. This research was partly initiated due to Finnish firefighters reporting difficulties in opening inward-opening apartment doors during emergency response operations.

The study included a series of tests conducted in an approximately 60 m² apartment, with various ventilation scenarios including fully open, normally designed, and completely closed ventilation ducts. It was observed that the pressure build-up in many cases was so significant that opening the door became difficult before the building structure failed (e.g., when windows broke). This indicates that inward-opening doors may not be suitable for small spaces with limited pressure relief options and where rapid fire development can be expected.

EVACUATION EXPERIMENTS

Description of premises and participant data

Evacuation experiments were conducted at the Västra Stallet premises in Stockholm, managed by the Swedish National Property Board. The facility includes a door situated between two larger rooms, allowing for tests involving both inward- and outward-opening door configurations. Additionally, the area in front of the door provided sufficient space to explore various adjacent room layouts and assess their influence on the evacuation process. Figure 2 illustrates the setup, with the test door highlighted by a red circle.

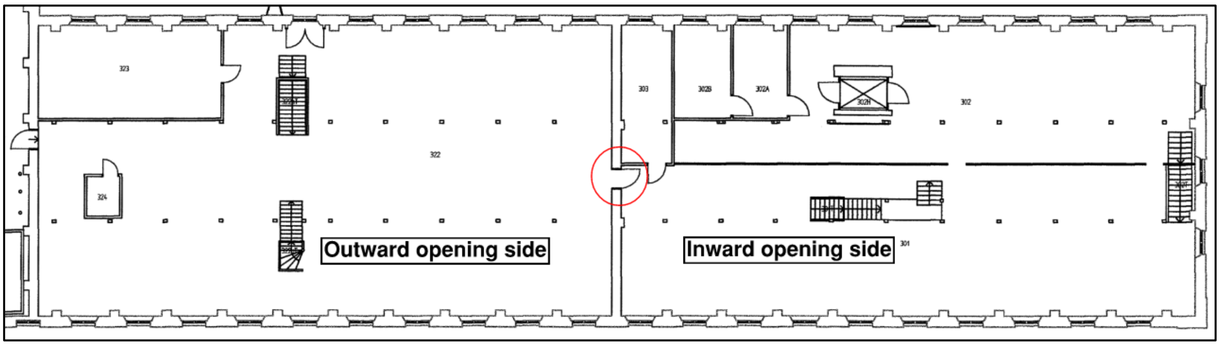

Figure 2. Layout of the premises.

A total of 95 participants attended the evacuation experiments. The participants had an even gender- and age distribution, see figures below. The study did not include persons with any movement impairment.

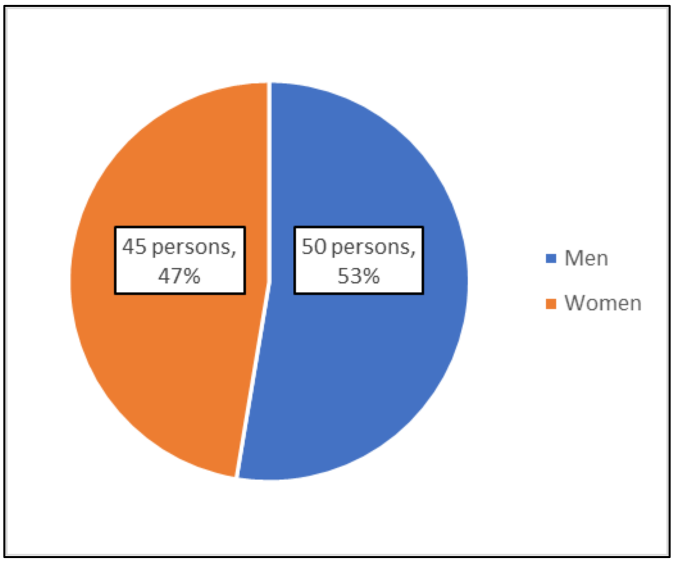

Figure 3. Gender distribution of participants.

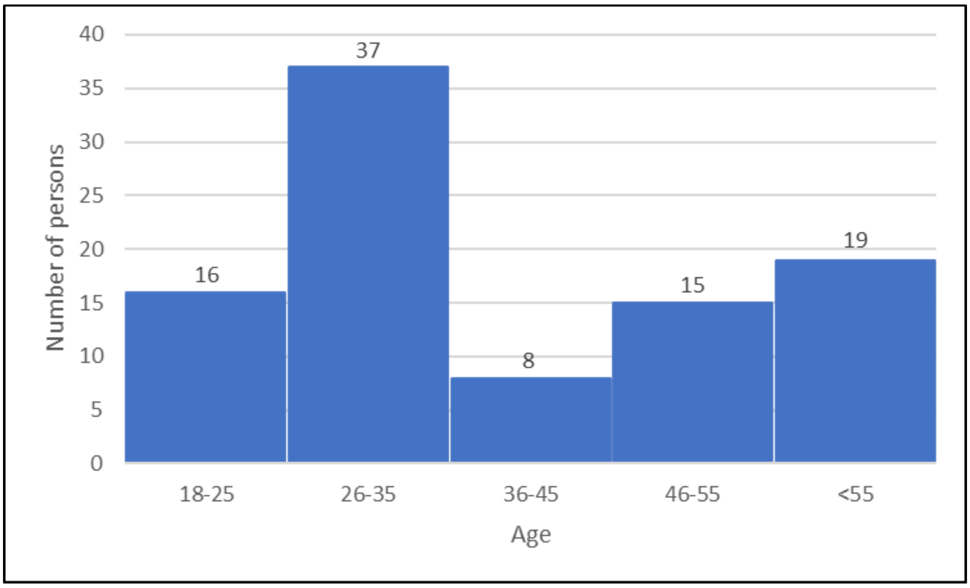

Figure 4. Age distribution of participants.

Scenarios

A total of 33 evacuation scenarios were conducted during the experiments. In each scenario, participants were instructed to move with purpose, simulating a deliberate decision to evacuate. They were explicitly told not to stroll or run. All participants began evacuating simultaneously at the sound of a whistle.

The following parameters varied between scenarios:

- Door swing direction
- Corridor/flow restrictor
- Walking distance
- Initial population density
- Number of participants
- Door fittings
- Door opening force

The following aspects were studied for each scenario:

- Group formations
  - Approaching the door
  - Passing through the door
- Door opening
  - Interaction between individuals
  - Occupant density
  - Time to open the door
- Flow rate
  - Overall flow rate
  - Initial phase

Results

The direction of door opening had no observable effect on the group formation as participants approached or passed through the door. However, inward-opening doors required more coordination between evacuees. The person opening the door had to stop and pull it open, requiring those nearby to slow down or pause in a greater extent than for outward opening doors.

The presence of a corridor results in a more organized, single-file group formation that transitions into a zipper pattern near the door. In contrast, scenarios without a corridor tend to exhibit immediate two-line or zipper formations before reaching the door. Corridor presence did not significantly affect occupant interactions, occupant density during door opening, or door opening time.

Longer walking distances result in a more defined triangular group formation figure 1), with lower occupant density at the front as people approach the door or corridor. Shorter walking distances tend to produce more chaotic and less structured group formations. Walking distance influence how many people needed to coordinate to open the door and the occupant density near the door. A distance of just five meters was enough to clearly observe these effects.

High initial occupant densities (especially with no or short walking distances) impacted the ease of opening the door, the number of people needing to interact, and the time to open it. When walking distance was present, the effect of initial density was less pronounced, likely due to natural group restructuring during movement.

The number of people had no significant impact on interaction levels or door-opening time, or people flow through the door.

The type of door fittings had a notable impact on both interaction and time needed to open the door. Knob-style handles required more coordination and resulted in slower opening times. This may lead to difficulties in opening the door when people behind catches up with the first person opening the door.

Door opening force did not have a clear effect on door-opening performance or people flow through the door within the tested range (40-100 N).

CONCLUSIONS

Based on observations from the literature review and evacuation experiments presented above, it is assessed that evacuation through inward-opening doors may be acceptable even for larger groups of evacuees, provided that the following conditions are met:

1. The door is equipped with fittings that allow for quick and effortless one-hand operation.
2. The occupant density near the door does not exceed approximately 3 persons/m^2.
3. The premises do not favour rapid fire development.

The second condition can be met, for example, by extending the walking distance before reaching the door or by introducing physical elements near the door to naturally regulate and reduce the flow of people. It is, however, considered essential that the introduced flow-restricting function does not encroach upon the required free evacuation width and that they can be expected to remain effective over time. This is particularly crucial when elements such as vestibules and fixed furnishings serve as flow-restricting features.

EXAMPLES

The following features are favorable for allowing evacuation through inward-opening doors and could be assessed when performing performance-based design.

Having a certain **walking distance** to the door is beneficial for the ability to open it, as the occupant density at the front of the group formation decreases with increased walking distance. Favorable patterns have been observed with as little as five meters between the area where people are positioned and the door, making this distance a useful reference in performance-based design. Furthermore, occupant density at the front of the group continues to decrease with even longer walking distances.

Various types of **flow restrictions** encountered before the evacuating group reaches the inward-opening door can improve the feasibility of accepting evacuation through such doors. Flow-restricting elements such as corridors, door openings or similar appear to positively influence the structure of group formations and help maintain a walking distance to the evacuation door. These effects lead to several improved evacuation conditions, including better flow through the opening and easier communication among evacuees. It is, however, considered essential that any added flow-restricting features do not encroach upon the required free evacuation width.

Inward-opening doors intended for evacuation must be equipped with **simple and intuitive one hand door fittings**. Examples of acceptable fittings include basic push handles or emergency exit devices. Opening mechanisms that require a two-handed operation, such as knobs, keys, or similar devices, pose a risk of delaying door opening, which could lead to unfavourable occupant densities and obstructive queuing. In this context, the level of familiarity with the premises is also likely to influence the effectiveness of the evacuation. However, direct differences in door-opening performance based on this factor have not been explicitly examined in previous studies.

Premises where inward-opening doors are used should generally have a relatively **large volume and/or feature slow fire development**. This is because rapid fire progression or confined spaces can lead to high fire induced pressures against inward-opening doors, potentially making them difficult to open. Environments that naturally relieve pressure, such as open spaces, large-volume rooms, areas with significant ventilation to the outside, or outdoor settings, help prevent the build-up of high fire induced pressure against the door. Likewise, premises with slow-developing fires, such as evacuation routes or unfurnished communication areas, offer favourable conditions for the use of inward-opening doors.

Figures 5–9 present examples of favorable conditions for the use of inward-opening doors in evacuation scenarios.

Figure 5 shows a typical small office setup. Flow restriction is achieved through room geometry, along with a layout that allows for a walking distance of more than five meters to the evacuation door. The positive effects associated with this type of setting are based on the assumption that occupant density in the reception area is low or nearly negligible.

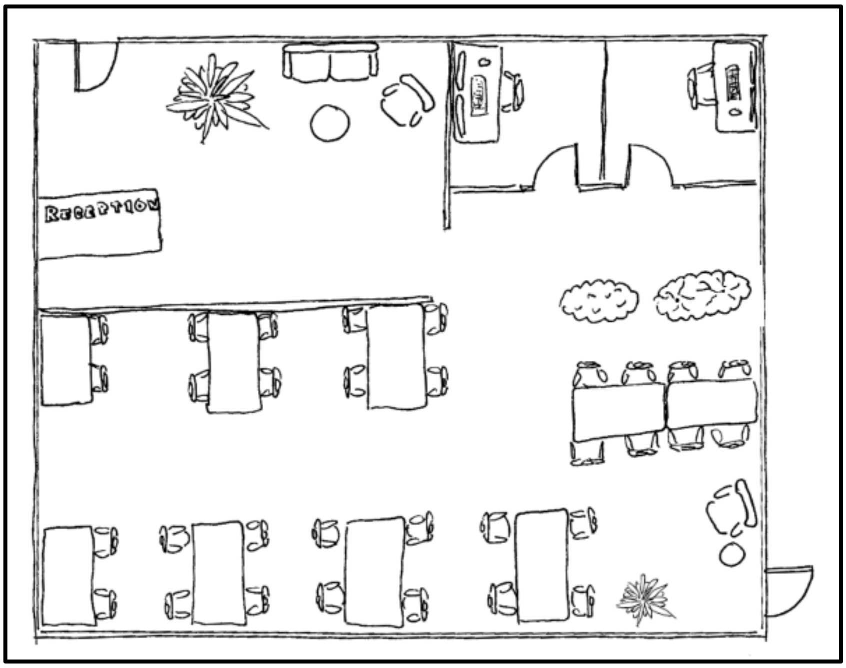

Figure 5. Office space.

In figure 6, flow restriction caused by room geometry is presented. This flow restriction will contribute to a more structured movement of people approaching the door, reduce the risk of high occupant density directly in front of the door, and ensure a certain walking distance from the area where individuals are initially located.

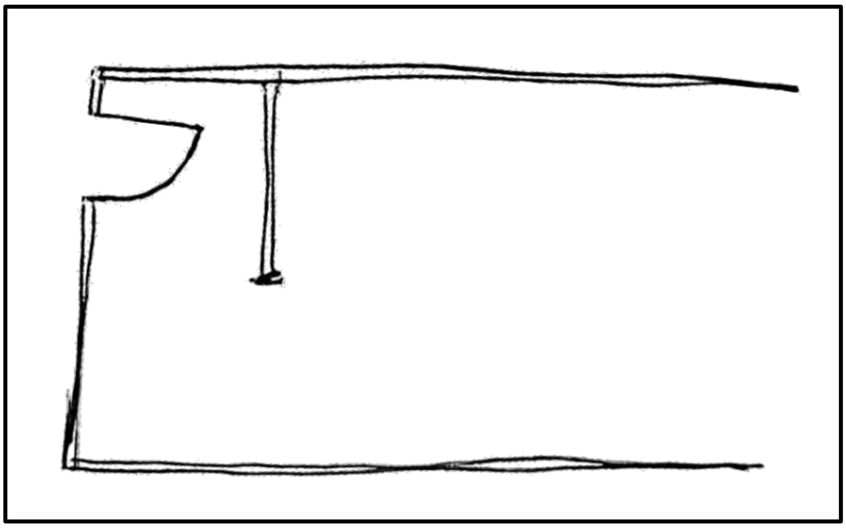

Figure 6. Flow restriction.

Figure 7 show an evacuation route in the form of a spiral staircase and an evacuation corridor. Flow restriction is achieved through the presence of a corridor connecting the stairwell to the room, in combination with a spatial configuration that provides a walking distance of over five meters to the evacuation door. This arrangement supports more orderly occupant movement, reduces the likelihood of crowding near the exit, and promotes favorable conditions for the use of inward-opening doors during evacuation.

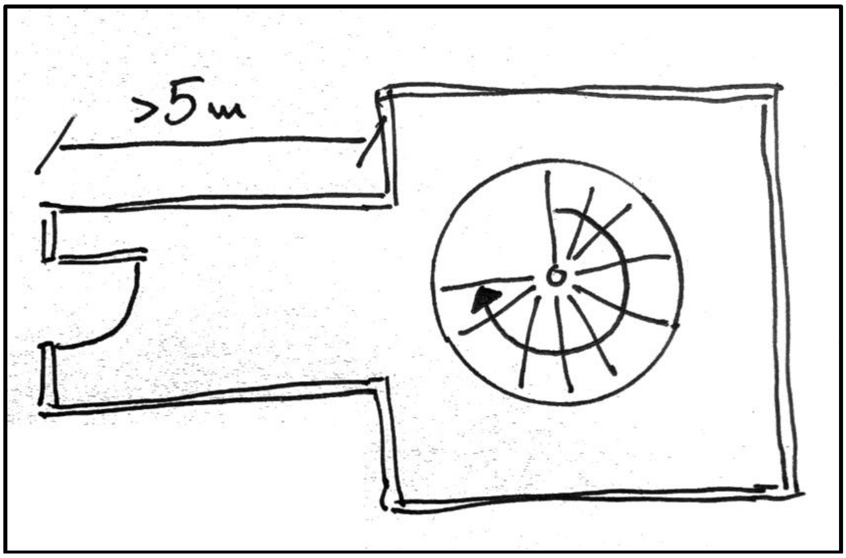

Figure 7. Evacuation route.

Figure 8 illustrates the recommended design of door fittings that ensures a simple one-handed opening operation.

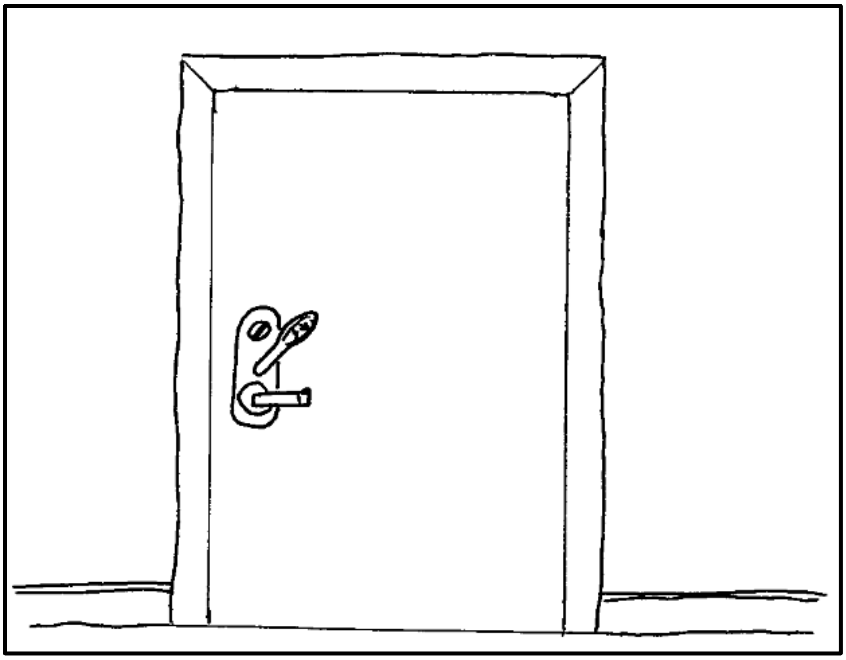

Figure 8. One hand door fitting (SS-EN 179).

Figure 9 illustrates a space of large volume with considerable potential for natural pressure relief, which helps ensure that rapid fire growth does not result in elevated fire pressure against the inward-opening door.

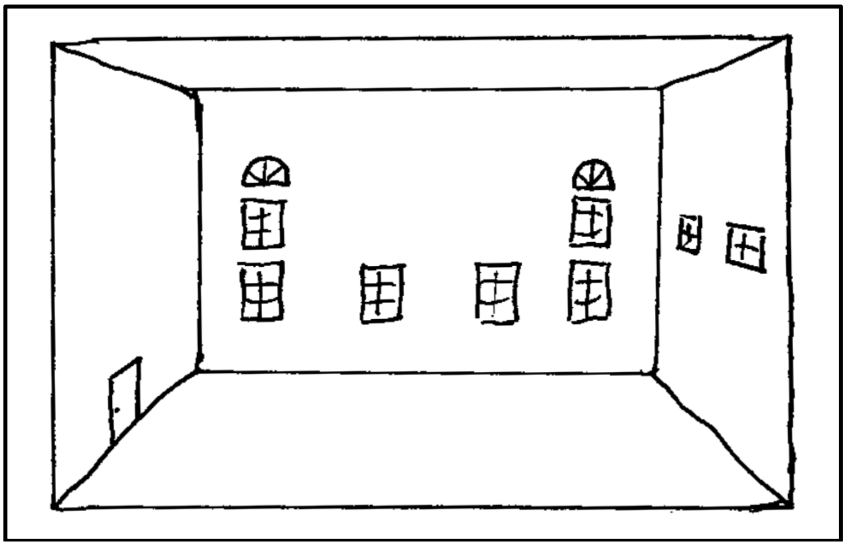

Figure 9. Large volume.

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