EFFECT OF CORNER ON EVACUATION BEHAVIOUR DURING BUILDING EGRESS BY USING DEM-BASED MULTI AGENT MODEL

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2017

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2017

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2014/2015

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Effect of Corner on Evacuation Behaviour During Building Egress by Using DEM-based Multi Agent Model

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ACKNOWLEDGEMENT

In the name of Allah, the most Merciful and Beneficent First and Foremost praise is to ALLAH, the Almighty, the greatest of all, on whom ultimately, we depend for sustenance and guidance. I would like to thank Almighty Allah for giving me opportunity, determination and strength to do my research. His continuous grace and mercy was with me throughout my life and ever more during the tenure of my study. I hereby would like to thank my supervisor for her guide towards finishing my study. With the proper guidance, I managed to finish my study on the appointed topic and gain knowledge towards finishing this thesis. I also appreciate the facilities provided from Pusat Pengajian Kejuruteraan Awam (PPKA), Universiti Sains Malaysia (USM) for all the things that facilitated smooth work of my research. Besides, I would like to give my gratitude to my parents for their moral support and financial expenses. Not forgotten, I would like to give credit to the lecturers and staff of PPKA for their direct and indirect helpful hand. Finally, I would like to thank my colleagues and friends for discussions, suggestions and criticism.

ABSTRAK

Tesis ini tertumpu kepada kajian mengenai kesan penjuru kepada kelakuan pemindahan semasa keluar dari bangunan. Kajian kes telah dijalankan di Pusat Pengajian Kejuruteran Awam (PPKA). Objektif kajian ini adalah untuk menentukan kapasiti penjuru, mencari ketumpatan nilai ambang berhampiran penjuru semasa pemindahan keluar dari bangunan dan menentukan lebar kritikal yang berkaitan dengan bilangan pejalan kaki yang berbeza. Simulasi andaian suasana pemindahan di penjuru dijalankan dengan bilangan pejalan kaki yang berbeza dan lebar penjuru yang berbeza. Had kajian ini adalah bilangan pejalan kaki dan lebar penjuru. Sejumlah 27 simulasi telah dianalisis menggunakan domain cubaan yang dicadangkan berdasarkan lebar yang berbeza (1.50m, 2.25m dan 3.00m) dan bilangan pejalan kaki yang berbeza (60,65,70,75,80,85,90,95 and 100). Simulator 'Crowd Behaviour Simulator for Disaster Evacuation (CBS-DE)' dengan penambahan alat bantuan dipanggil 'Human Behaviour Simulator (HBS)' digunakan untuk menganalisa kelakuan pemindahan. Hasil yang diperolehi daripada simulasi tersebut adalah masa yang diambil untuk keluar dan daya interaksi. Hasil kajian menunjukkan tiada kesesakan dan penyumbatan yang menunjukkan ketumpatan nilai ambang kerana bilangan pejalan kaki tidak cukup untuk menghasilkan kesesakan dan penyumbatan. Di samping itu, Inter 9 menunjukkan graf siri masa untuk maximum daya interaksi yang terbaik kerana menunjukkan peningkatan nilai daya interaksi jika berlaku penurunan lebar penjuru dan nilai maximum daya interaksi tidak melebihi had daya interaksi. Kajian kes menunjukkan dengan mengkaji jalan keluar alternatif dapat meningkatkan kecekapan proses pemindahan keluar di tingkat bawah PPKA.

ABSTRACT

This thesis focuses on the effect of corner on evacuation behaviour during building egress. The case study is conducted at Pusat Pengajian Kejuruteraan Awam (PPKA). The objectives of this study were to quantify the capacity of corner, determine numerically the threshold density near the corner during building egress and determine the critical width related to different density of pedestrian. Simulation of hypothetical evacuation scenarios at corner was carried out based on different pedestrian density and different widths. The main parameters of this study are the pedestrian density and width of corner. A total of 27 simulations had been performed on the trial domain with three different width and nine different pedestrian density. Crowd Behaviour Simulator for Disaster Evacuation (CBS-DE) with the additional tool called Human Behaviour Simulator (HBS) was used to analyse the evacuation behaviour. The results of the simulations were egress time and interaction force. The findings show that there are no series of jamming and clogging that indicate the threshold density since the pedestrian density may be not sufficient to cause jamming and clogging. Meanwhile, Inter-9 shows the best time series of the maximum interaction force graph with pattern of increasing maximum interaction force as the corridor width decreases and the interaction force did not exceed the upper and lower limit of contact force. From the case study, it is found that the alternative evacuation route can improve the evacuation process at the ground floor of PPKA.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AE	Adobe **A**fter **E**ffect
CBS-DE	**C**rowd **B**ehaviour **S**imulator for **D**isaster **E**vacuation
DEM	**D**istinct**-E**lement**-M**ethod
FEM	**F**inite-**E**lement-**M**ethod
HBS	**H**uman **B**ehaviour **S**imulator
HCM	**H**ighway **C**apacity **M**anual
NOP	**N**umber **o**f **P**edestrian
NPRA	**N**umber of **P**edestrian Who Have **R**eached The **A**ppointed Safety Place
PPKA	**P**usat **P**engajian **K**ejuruteraan **A**wam
UBBL	**U**niform **B**uilding **b**y **L**aw

NOMENCLATURES

$\boldsymbol{v}$	Velocity
t	Time
v_x	Velocity in x direction
v_y	Velocity in y direction
Δx	Difference in x direction
Δy	Difference in y direction
Δt	Difference in time
m_{hi}	Mass of person *i*
I_{hi}	Moment of inertia of person *i*
$\boldsymbol{v}_{hi}$	Velocity of person *i*
$\boldsymbol{F}_{awhi}$	Driving Force of person *i*
$\boldsymbol{F}_{inhi}$	Inter-element force acting on person *i*
$\boldsymbol{\omega}_{hi}$	Angular velocity of person *i*
$\boldsymbol{T}_{hi}$	Torque acting on person *i*
$\boldsymbol{v}_{limit}$	Specific equilibrium velocity
$\boldsymbol{V}_{max}$	Maximum velocity
γ	Proportional coefficient
C_k	Density of persons inside the perception domain
$\boldsymbol{F}_{ij}$	Physical repulsive force between person *I* and person *j*
$\boldsymbol{F}_{iw}$	Physical repulsive force acting between a virtual wall element *W* and person *i*
$\boldsymbol{F}_{psij}$	Psychological repulsive force acting between person *i*
$\boldsymbol{f}_{ij}$	Local physical repulsive force acting between person *i* and person *j*

$\boldsymbol{f}_{iw}$ Local physical repulsive force acting between person *i* and a virtual wall element *W*

$\boldsymbol{f}_{psij}$ Local psychological repulsive force acting between person *i* and person *j*

$\boldsymbol{r}_i$ Positional vector of the person *i*

$\boldsymbol{r}_w$ Positional vector of the virtual wall element *W*

CHAPTER 1

INTRODUCTION

1.1 Background

A corner facility or an L-shaped geometry is a common facility found in most buildings. Logically, we can assume that there will be changes to the human walking velocity, like slow down effect, when approaching and walking through the corner due to turning movement that pedestrian need to perform near a corner. This situation subsequently will trigger restrictions to pedestrians flow. Thorough understanding of pedestrian flow for any geometrical shapes in a specific building is crucial since it is a basis in determining and evaluating the evacuation behaviour of pedestrians.

Studying the effect of a corner on evacuation behaviour is rare compared to other types of facilities, like straight corridor and T-shaped intersection. Hence, corner effect on evacuation behaviour of pedestrians should be further studied since the empirical relation between density and velocity of pedestrian motion in relation to pedestrian interaction, which determine the relation at medium and high densities, is not yet completely analysed. An L-shaped or a corner is a common geometrical condition that is frequently found in all kinds of buildings, for instance, a corner of the emergency staircase which is usually located at building edges (end of the building), and an L-shaped facility of the corridor.

To facilitate this study, a microscopic particle-based model which is the Distinct Element Method (DEM)-based Crowd Behaviour Simulator for Disaster Evacuation (CBS-DE) model is used. The model is capable of modelling each individual distinctly by tracking the trajectory and rotation of each individual in the domain. Crowd Behaviour Simulator for Disaster Evacuation (CBS-DE) has been developed at at Laboratory of

Professor Hitoshi Gotoh in Kyoto University. It has been used in studying many evacuation process scenarios like in Gotoh et al. (2004, 2008, 2009, 2012), and Harada, 2015. In this study this simulator is used to simulate the scenario of pedestrians walk near L-shaped facility and also is used to simulate the evacuation process scenario at the PPKA building.

1.2 Problem Statement

Corner is one of the geometrical conditions or facilities that could trigger restrictions to pedestrians flow and can always jammed during rush hour, like at schools. Many recent studies focus in straight corridor and bottleneck effects on pedestrians flow and dynamics like Chen et al. (2014). However, study on the effect of L-shaped on pedestrian flow and evacuation behaviour of pedestrians is comparatively rare. It is believed that corner should be further studied since the empirical relation between density and velocity of pedestrian motion in relation to pedestrian interaction, which determine the relation at medium and high densities, is not yet completely analysed. The obtained empirical results thus allow estimation of evacuation efficiency and improvement on the safety and comfortable level of crowded evacuation in a building.

1.3 Objective

The objectives of this study are listed below :

1. To quantify the capacity of the L-shaped facility,
2. To determine numerically the threshold density in which occupant would be jammed and clogged near the corner during building egress;
3. To determine a corresponding critical width related to different density of pedestrians.

1.4 Scope of Study

The implementation strategies of this research are two-pronged. First, the unidirectional flow experiment on walking pedestrians at the corner for different pedestrian density and corridor width will be performed. The empirical results obtained are used to verify the reliability of the model. Secondly, numerical simulations of hypothetical evacuation scenarios at the corner in a building are performed for different pedestrian density, distribution and corridor width. This is to estimate evacuation time, and examine the corresponding critical width related to different density of pedestrians.

This study focuses on a corner facility or an L-shaped geometry facility of a building with varying exit width and number of pedestrians. This study examines the effect of a corner on evacuation behaviour during building egress using CBS tool (in house developed tool) and Autodesk MAYA (MAYA) for experimental based analysis, modelling and simulation. The research is carried out at a building of School of Civil Engineering, Universiti Sains Malaysia. To facilitate this study, a CBS-DE model is employed to simulate the evacuation process in a building under different pedestrian density, distribution and corridor width. From the simulation, the evacuation time can be obtained and analysed.

1.5 Significance of Study

The capacity of evacuation behaviours at corner facilities during building egress can be quantified in this study. Threshold density can help in reduce the potential accident during evacuation process. Knowing the threshold density can help in limiting the number of pedestrian at a corner during emergency evacuation to increase the efficiency of evacuation process. This research may be helpful in determining the critical width of corner facilities with respect to distribution and pedestrian density for evacuation efficiencies to improve the safety and comfortability level of crowded evacuation in a building.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The topic related to the research for evacuation behaviour in a building is reviewed and discussed. Besides, the corner facility which includes the effect of geometrical facilities to the pedestrian flow, capacity and threshold density of facility is reviewed. Furthermore, the evacuation behaviour at other facilities such as T-shaped and bottleneck and the current available simulator which simulates the evacuation behaviour is touched.

2.2 A Corner Facility

Corner facility or L-shaped facility is one of the most common facility that can be found in a building besides T-shaped and straight facilities. Most of a corner are at 90° and located at the end of a building.

2.2.1 Effect of Geometrical Facilities to The Pedestrian Flow

Geometrical facilities like T-shaped facility are commonly discussed by researcher. One of the study conducted by Tajima et al. (2002) said that the traffic flow on highway is typically one-dimensional but the pedestrian flow is two-dimensional. The pedestrian flow within a channel or underpass is closely connected to the granular flow. A computer simulation for pedestrian flow in the T-shaped facility was carried out by Tajima et al. (2002). The research was focused on the pedestrian flow rate where the schematic illustration of the T-shaped facility is shown in Figure 2.1 where L = 200 and $W_a = W_b = 40$. Meanwhile, Figure 2.2 shows the walking pattern of pedestrian. Four distinct patterns appear in the T-shaped channel flow: (a) both low-density phases, (b) low-density phase in the main channel and high-density (clogging) phase in the branch channel, (c) high-density (clogging) phase in the main channel and low-density phase in the branch channel, and (d) both high-density (clogging) phases in the main and branch channels.

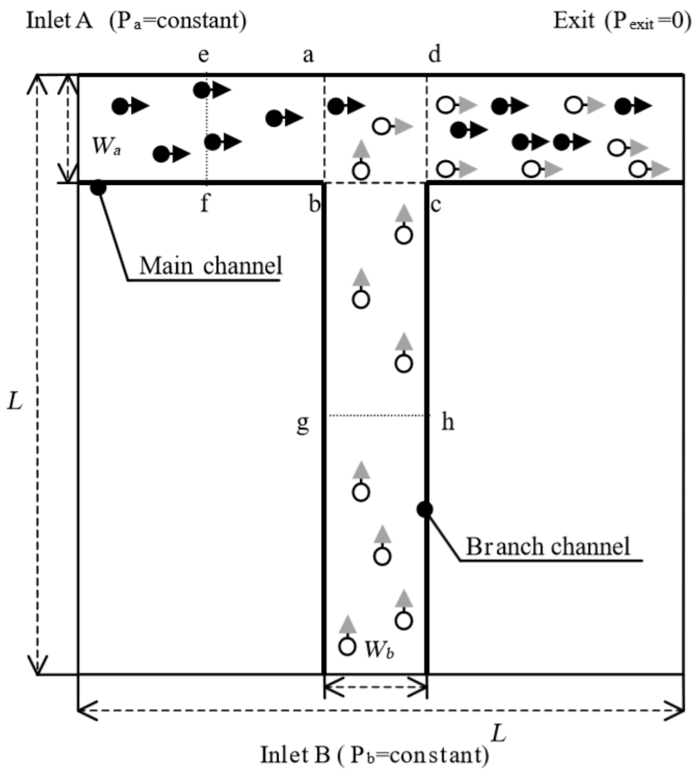


Figure 2.1 Schematic Illustration of The T-Shaped Facility.

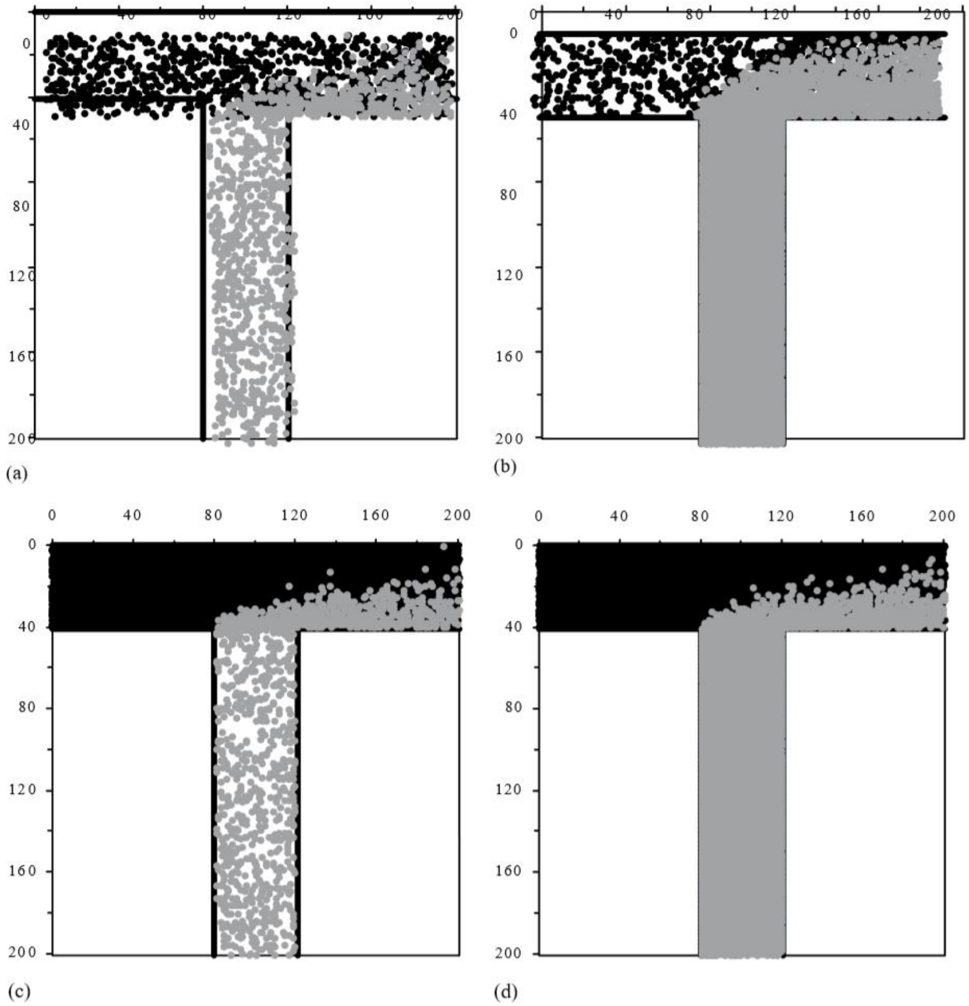
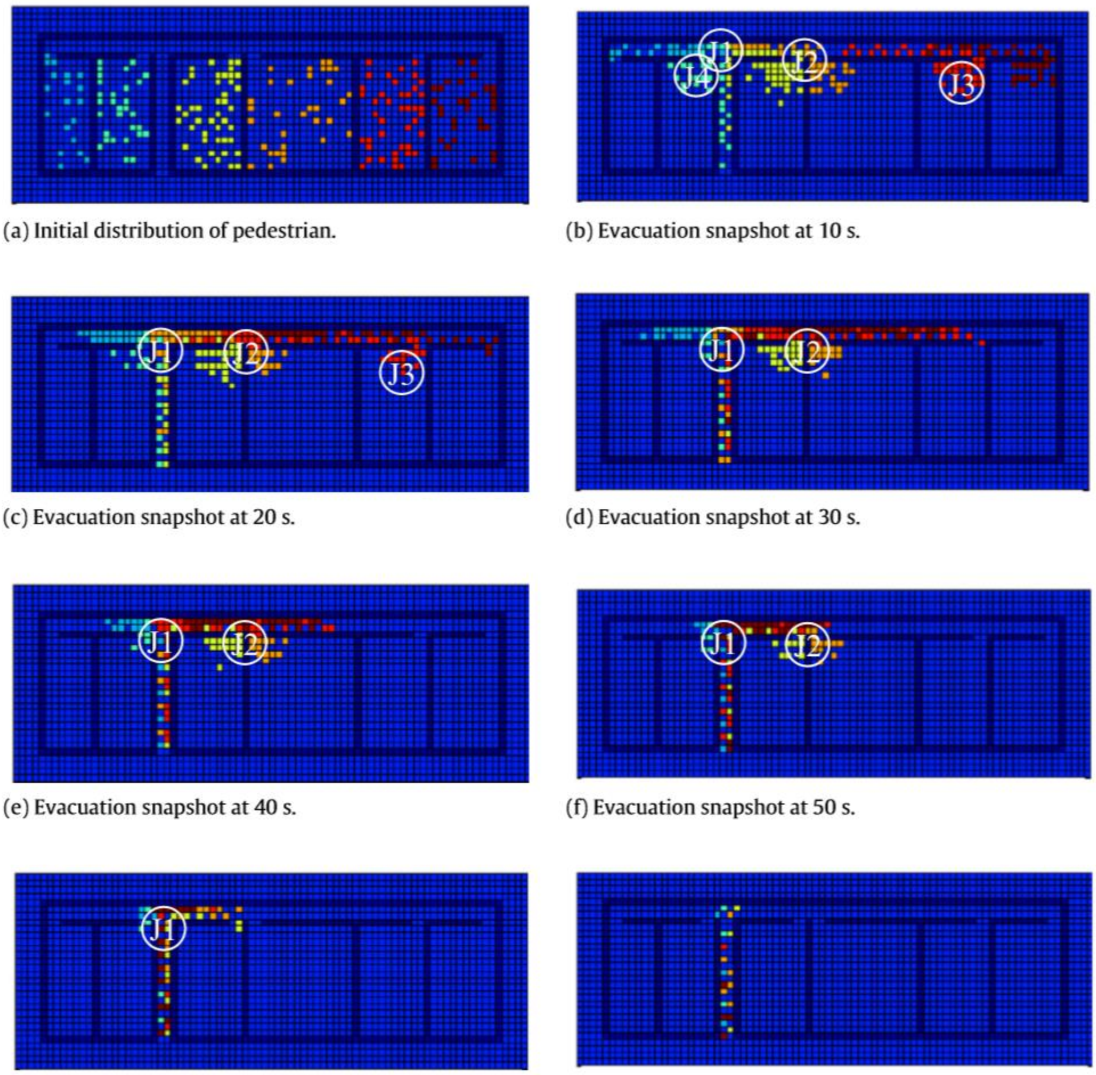


Figure 2.2 Walking Pattern of Pedestrian ((a)inlet density $P_a = 0.1$ and $P_b = 0.1$, (b)inlet density $P_a = 0.1$ and $P_b = 0.4$, (c)inlet density $P_a = 0.8$ and $P_b = 0.1$, (d)inlet density $P_a = 0.8$ and $P_b = 0.5$).

Chen et al. (2012) who studied the effect of T-shaped facility said the effect of geometrical facility were that the most serious jamming actually happened at the entrance of the emergency staircase which is a typical kind of T-shaped channel. The entrance of staircase was jammed from 10s after the beginning of the evacuation until 60s as illustrated as J1 marked in Figure 2.3. Hence, it is sure that the T-shaped channel is indeed hazardous for the evacuation of pedestrians, where the jamming and collision would occur easily. Furthermore, the door of Room3 and Room4, which is another typical kind of T-shaped channel in the building, are also jammed seriously from 10s to 50 s as marked as J2 in Figure 2.3, which causes the persons in the above rooms to reach the corridor much more difficult. The door of Room2 and Room5 which is the kind of T-shaped channel similar to Room3 and Room4 are also jammed as shown as J3 and J4 marked in Figure 2.3. But the situation is not as serious as that of Room3 and Room4 for the jammed rescinds before 30s after the beginning of evacuation. In addition, the pedestrians at the door of the rooms, which are located close to the emergency staircase, may be jammed due to great repulsion from the pedestrians passing through the front of the door in the corridor from the other rooms. It is difficult for them to walk out of the room during the evacuation.



(a) Initial distribution of pedestrian.

(b) Evacuation snapshot at 10 s.

(c) Evacuation snapshot at 20 s.

(d) Evacuation snapshot at 30 s.

(e) Evacuation snapshot at 40 s.

(f) Evacuation snapshot at 50 s.

(g) Evacuation snapshot at 60 s.

(h) Evacuation snapshot at 70 s.

Figure 2.3 Whole process of evacuation in numerical simulation when the DOP is 1.10person/m^2.

Jo et al. (2014) conducted four case study to crowd flow through a door. In case A, in order to confirm the change in the flow rate from the room in relation to a change in the crowd density in the corridor, the effective area of the corridor was changed. In case B, door A and door B were used to confirm the influence of people merging from the other rooms. In addition, an experiment involved changing the width of the door was carried out. In case C, it took time for the evacuees to enter the corridor when nobody was there already. Cases were also considered where the corridor was crowded from the outset. Figure 2.4 shows the effective area of the corridor to the pedestrian flow.

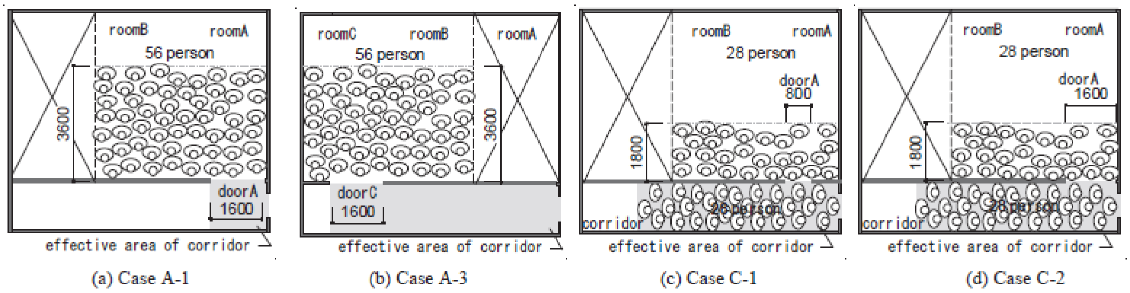


Figure 2.4 Effective area of a corridor.

2.2.2 Capacity of The Facility

Capacity is defined as the ability to hold something or the maximum production attainable under normal conditions by referring to the engineering term. L-shaped facility is a common facility found in most buildings. However, study on the effect of L-shaped on pedestrian flow and evacuation behaviour of pedestrians is completely rare compared to straight and T-shaped facilities. The relationship between velocity and density of straight and T-shaped facilities is review in this sub-chapter.

Chen et al. (2012) found that the capacity of a T-shaped facility was about 0.50 persons/m^2 under the condition proposed in their study. If the number of person