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EVACUATION OF BEDRIDDEN OCCUPANTS

EXPERIMENTAL RESEARCH OUTCOMES



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ABSTRACT

Bedridden building occupants in hospitals and nursing homes who are not able to rescue themselves in case of a fire emergency require assistance during an evacuation. A building emergency team is usually fulfils this function and will have to remove the occupants from the room. The speed at which such an evacuation is conducted however is unknown. Experiment in practice were conducted in hospitals and nursing homes to obtain insight on the evacuation speed and absolute evacuation times required. Furthermore, a simulation was conducted of a hospital to obtain values on the available safe egress time. Comparing the experimental results with the simulation results indicates that a safe evacuation strongly depends on the arrival time of the building emergency team at the room in question. Furthermore the experiments showed that many of the people who conducted the evacuations were insufficiently trained for this.

1 INTRODUCTION

Research conducted by the Dutch *Ministry of Housing, Spatial planning and the Environment (VROM)* has shown that around thirty percent of the existing nursing homes and healthcare centres in the Netherlands something is wrong with the structural fire safety measures and direct governmental interference was necessary (VROM, 2011). From this research it was also made clear that 81 out of the 93 investigated nursing homes and healthcare centres has some sort of shortcoming in regard to smoke and/or fire compartments. Less than half (42) out of the 93 investigated buildings has a sub- fire and smoke compartment for the bedbound occupants, which is a statutory regulation. However, the report furthermore shows that in half of the investigated

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buildings, the Building Emergency Team (BET) was well informed. The trend of decreasing structural fire safety can be seen not only at the investigated nursing homes and healthcare centres, but also at other similar buildings throughout the country. This situation creates potentially dangerous scenarios if a fire would occur in such a building, especially for the occupants who are not capable of rescuing themselves. They then rely on the BET to help them evacuate the building. However, as stated before, also in a large part of the nursing homes the BETs are insufficiently instructed and the risk assumptions are proven to be inadequate. In general though, one can say that a BET in a healthcare centre is most likely to be better organized than a BET in a nursing home, because a healthcare centre is constantly occupied and operates twenty-four hours a day. It is therefore important to create a fire safe environment for these occupants, and especially for the occupants who are not able to rescue themselves in case of an emergency. The sub-questions that arise within this research are: ‘What is the evacuation speed of a bedridden building occupant?’ and ‘How long is the Available Safe Egress Time (ASET) in a common hospital?’. These questions are answered by conducting an experimental research on the evacuation speeds of bedridden building occupants, from which it is analysed whether it is possible to determine the Required Safe Egress Time (RSET). The RSET is then compared to the ASET, which is achieved by simulating a case study, and compared to the experimentally obtained results.

2 METHODOLOGY

To determine an average evacuation speed of bedridden building occupant evacuation drills in hospitals were performed. Volunteers were searched for participation where the research could be conducted and collect the required personnel within the hospitals to execute this evacuation drill. The measurements were conducted under strict conditions to be able to compare results from different buildings with one another.

An experiment is set-up to retrieve evacuation speeds of bedridden building occupants. This experiment is conducted in a room within a fire compartment. Although the setting is different in every situation, figure 1 can be used to schematically describe the principle of this experiment. The results of all experiments are furthermore depending on the people executing the evacuation and the incidental mistakes that can occur.

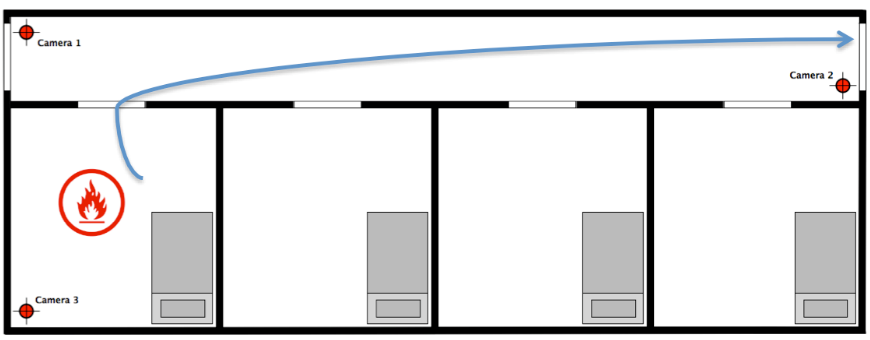


Figure 1. Schematic representation of the experiment.

An evacuation with bedridden building occupants is imitated by evacuating one room in which at least 1 hospital bed is positioned. On the bed a person or dummy has to be placed in order to imitate the real weight that is delaying the movements of the evacuating people. The bed, with the person or dummy, is moved through the hallway and is brought outside the fire compartment. The evacuation scenario can be used with 1 bed but also with e.g. 4 beds in a room, and can be replicated in different hospitals.

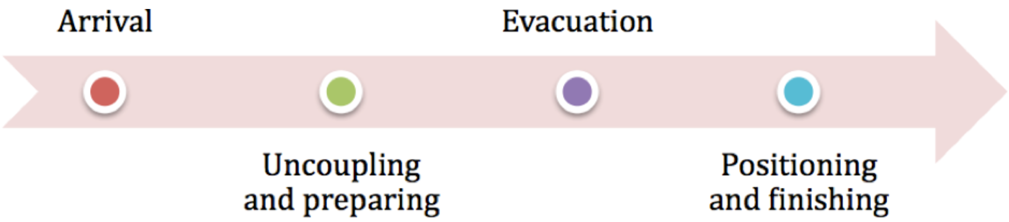


Figure. 2. The evacuation scenario.

The evacuation scenario of a bedridden building occupant can be divided in four steps, according to figure 2. The procedure will begin outside the fire compartment doors and two employees of the hospital will conduct the evacuation of the bed(s). They will get a sign to start the evacuation and move towards the first bed they will need to evacuate from the fire compartment; this stage of the experiment is defined as the 'arrival stage'. Following up they will need to uncouple the imaginary patient from a drip or perhaps an artificial respiration system. It can also occur that the bed requires electricity to change its stand, then the bed will also require to be uncoupled from the electricity grid; this second stage is defined as the 'uncoupling' stage. Afterwards the actual evacuation can begin; during this stage the bed is moved from the room, through the hallway and finally moved through the fire compartment doors. This stage is defined as the 'evacuation' stage. As a last the bed has to be positioned in such way that more beds can be evacuated and positioned behind the fire compartment doors; this part of the experiment is defined as the 'positioning' stage. In case more than one bed is evacuated from the room, the process is repeated as soon as the evacuating personnel move through the fire compartment doors again.
This whole scenario is recorded on three different cameras to determine the required time to evacuate one or multiple bed(s) out of the fire compartment. The evacuation speeds are later defined by measuring the travelled distances from a floor plan and divide the distance by the travelling time. The measurement results are processed by means of video-editing software and the absolute numbers are written down in an excel file.

3 RESULTS

The experimental results of the hospitals are referred to as numbers to avoid linking the measured results to certain hospitals.

	Evac. speed	Arrival speed	Uncoupling	Positioning	Total time
Mean values 1	0.80 m/s	1.33 m/s	6.83 sec	10.25 sec	66.25 sec
Mean values 2	0.88 m/s	2.04 m/s	17.6 sec	7.18 sec	50.59 sec
Mean values 3	1.02 m/s	2.20 m/s	5.18 sec	5.97 sec	48.43 sec
Mean values 4	0.84 m/s	2.13 m/s	4.69 sec	9.04 sec	40.36 sec
Mean values 5	1.14 m/s	1.62 m/s	81.89 sec	5.73 sec	126.05 sec

Table 1. Mean values of all five hospitals.

4 DISCUSSION

Hospital #1

The evacuation scenario was conducted by two men of 45 and 54 years old, who both had much experience in conducting evacuations (both had participated in evacuation-drills over 14 times). One of them conducted an actual evacuation during a fire emergency situation, and both had experienced fire emergency situations. In total they have evacuated three beds in four rounds.

Furthermore, their profession at the hospital involves coordinating the hospital its BET and one of them is involved in the voluntary fire department. The experience both men had with conducting evacuation drills probably also affected their speeds; they moved relatively slow (normal pace) towards the room that was subject to evacuation. Also, during the arrival stage at the start of each new round, one of them felt the door by hand, which is common practice for each BET member. Furthermore a wheelchair user blocked the evacuation route once and the arrival stage was hindered another two times.

Hospital #2

Four women of 26, 30, 35, and 38 years old who had no experience at all with evacuation drills or any other emergency situation conducted the evacuation scenario. All four women have a nursing and caring profession at the hospital, in the same department in which the drill was conducted. Two women conducted the evacuation each round, for a total of five rounds. The group compositions however did not change during the rounds, so one group of two has conducted the evacuation three times while the other group did the evacuation scenario twice. The women conducting the evacuation were very eager to get “good results” and ran towards the room subject to evacuation. The evacuating personnel did not touch the doors prior to entering the room as they were told to. Furthermore, the uncoupling of the first bed took much too long and would not be realistic in a fire scenario. During one evacuation the cable jammed the wheel of the bed.

Hospital #3

Evacuation measurements in this hospital were conducted two times on different days, but in the same compartment and room. Two men and two women of respectively 44, 51, 29 and 34 years old, who all had much experience with evacuation drills, conducted the first evacuation procedure.

Three men and three women conducted the second evacuation measurement, from whom two also participated in the first evacuation measurement. The three men and three women were respectively 25, 44, 45 and 21, 22, and 34 years old. The man and woman who also participated in the previous evacuation measurement have very much experience in evacuation drills, and from the newly added people only one has much experience, one has participated in an evacuation drill once and the other two were not familiar with the evacuation procedure at all. The woman of the first evacuation measurement conducted the first three rounds in collaboration with the man of 45 who had relatively much experience. The man who also participated in the first measurement together with the man of 25 years old conducted the following two rounds.

The two measurements were combined to analyse a total of 39 evacuation measurements, conducted by 8 people in total.

Hospital #4

A man and a woman of respectively 33 and 52 years old conducted the experimental evacuation scenario in this hospital. The woman had experienced an evacuation drill with bedbound patients once while the man had no experience in evacuating a bedbound patient. The man had furthermore participated in an evacuation drill twice, while the woman participated in an evacuation drill once but has also experienced an actual fire emergency in which she did not evacuate any people. In total they have evacuated four beds in five rounds. Furthermore, their profession at the hospital involves nursing hospital patients.

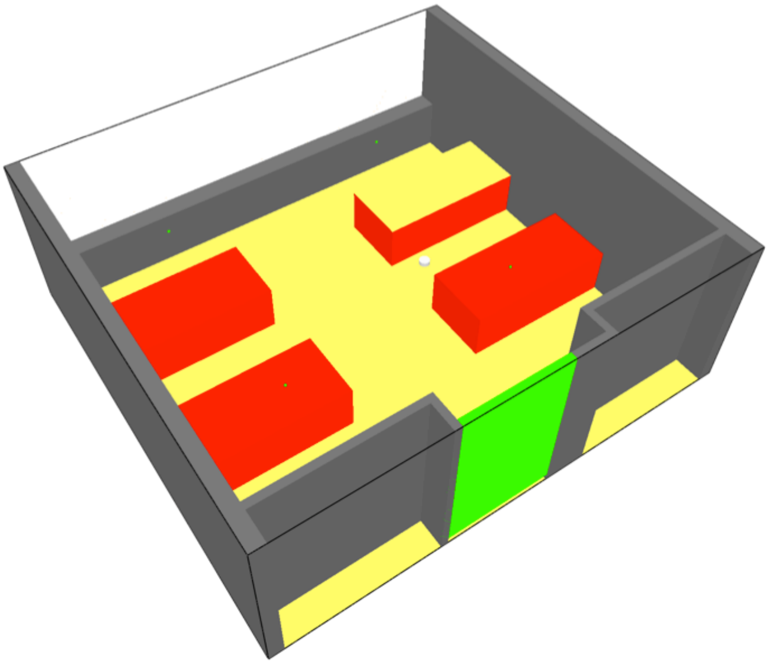
Hospital #5

The fifth evacuation measurement at a hospital is one that cannot be compared to the other measurements because the drill was held at an intensive care (IC). 2 men and one woman of respectively 45, 34, and 31 years old conducted the drill. The younger man and woman had experienced an evacuation drill with a bed once, while the older man had no experience in conducting an evacuation. None of them have experienced an actual fire emergency situation. Even though all three persons have much experience in moving hospital beds because their profession involves nursing IC patients. In total, two beds were evacuated in five rounds.

Two dummies were used for this evacuation drill because it is easier to connect them to the different pumps and devices that are generally in use on an IC patient. Both teams were told to uncouple the patients as quickly as possible, but in a well-considered way: as if it were a real patient that could be harmed if anything went wrong.

5 SIMULATION

A simulation of a case study is conducted in the computer program ‘Fire Dynamic simulator’ (FDS). FDS uses the Large Eddy Simulation (LES) method to solve its input. One case study is investigated with different settings to analyse the distribution in the outcome. The simulation is performed to retrieve an ASET on the case study. The simulation model is set up from the ground plan and additional data from the hospital measurements taken at hospital #2. The simulation initiates at t=0 seconds with a pre-defined heat release rate and time constant as described in paragraph 2.2. One should note that the smouldering phase therefore is skipped and the fire might already be detected. Because one cannot judge when the fire would be detected, t=0 is taken as the point where the fire probably would be detected by either the patients inside the room (this would involve a detection and response time of the person) or by the smoke detector. It is assumed that the people inside the room are bedbound and cannot evacuate themselves. Help is assumed to arrive at the scene within 60 seconds after t=0.
The simulation model is set-up from a ground plan of a hospital in which also an experimental measurement has been conducted. The visualization of the FDS model is shown in figure 4.



Model with door closed constantly

Model #1 = RHR 100 / t_α 300
Model #2 = RHR 250 / t_α 300
Model #3 = RHR 375 / t_α 300
Model #4 = RHR 250 / t_α 100
Model #5 = RHR 250 / t_α 600

Figure 4. An impression of the FDS simulation model (the four red areas are beds) and different simulation scenario’s

The dimensions of the model are 6.8 x 6.3 x 2.4 (XYZ) metres, the applied grid size for these dimensions are chosen through a sensitivity analysis. A few variants were simulated to obtain a kind of spreading on the simulation results. Variances were created on three levels: three amounts of RHR were simulated, three time constants were simulated, and a simulation is conducted in which the door is opened and closed according to the time that the evacuation team was inside the room. Fig. 4 gives an overview of the variants that are simulated and lists a reference number that is used to link it with the simulation results.
The visibility and temperature output is defined for all the simulation variants. The output is judged by analysing so called ‘slice-files’ in FDS that represent a cross section at 1.5 metres height (a person’s head height). An example of the judgement on the first simulation model is shown in figure for the 5 and in figure 6 for the 6 .23 metre soot visibility criteria.

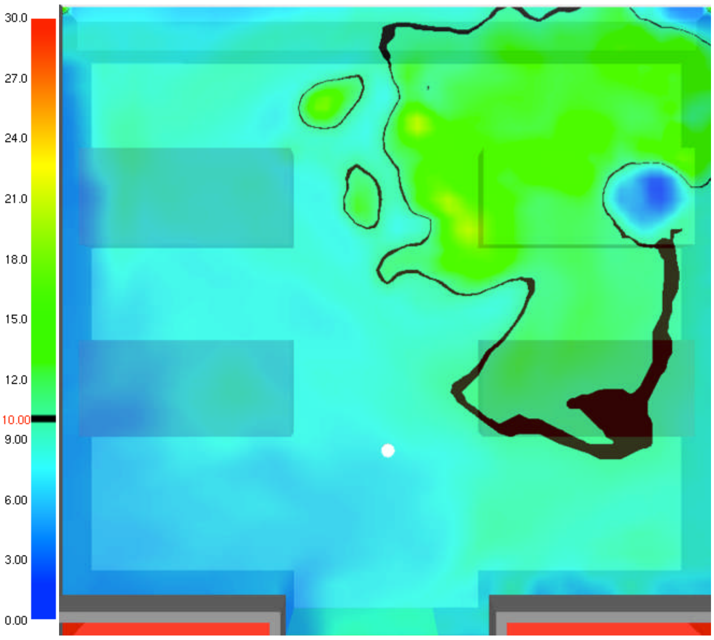


Figure 5. Soot visibility of model #1. The black line indicates the transition zone from a visibility of 10 metres or higher to a lower value.

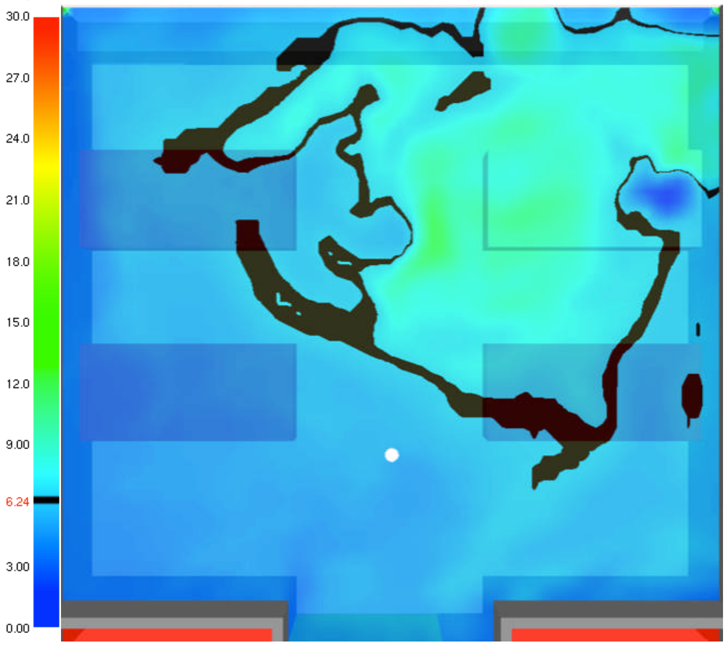


Figure 6. Soot visibility of model #1. The black line indicates the transition zone from a visibility of 6.23 metres or higher to a lower value.

Table 2 presents the results of the model in the case of the 5 different scenario's. .

Model:	#1	#2	#3	#4	#5
Visibility 10m	155	114	101	177	81
Visibility 6.23m	171	129	111	201	84
Temperature 150 °C	> 600	441	291	> 600	234

Table 2. Simulation results of the model with the door constantly closed; results in seconds.

It is shown from table 2 that visibility is a far more important parameter than temperature due to the fact that smoke development in general goes much faster than the temperature development in a room (depending on the material on fire). As is shown from the table the visibility criteria are met in 114 second for 10 meters and 129 seconds for 6.23 meters when applying the generally used fire conditions of 250 kW/m^2 and a time constant of 300 seconds (model #2). When the sheets and the beds would be made fire retardant a lower time constant or lower heat release rate is more probable. The visibility criteria are met at 177 seconds for the 10 meter criteria and 201 seconds for the 6.23 metre criteria for the model with a lower time constant (model #4). For the model with the lower heat release rate (model #1) the criterion for 10 meter visibility is met at 155 seconds and the criterion for 6.23 metre is reached at 171 seconds. These differences seem relatively small on an absolute scale, but can be lifesaving in emergency situations where every minute counts.

If the room would be filled with more obstacles and materials the heat release rate will become bigger and the fire spread rate might increase. Model #3 is calculated with a higher heat release rate and shows that the time until the criteria are reached drops to 101 seconds for the 10 meter visibility and to 111 seconds for the 6.23 meter visibility criterion. When the fire spread rate would increase to a fast developing fire (model #5) the time to reach the criteria drops even lower to 84 seconds for the 10 meter criterion and to 83.4 seconds for the 6.23 meter criterion. These two conditions however most often are not applicable to hospital rooms, but can be applicable in case a room in a nursing home is simulated where the fire load is much different from a hospital room.

6 CONCLUSIONS

The evacuation speed results in hospitals show that fifty percent of the outcomes lie in a range of 0.81 to 1.01 metres per second with peak values on both sides of the range. The fifty percent range is however quite an accurate assumption for "clean" (without hindering of any sort) evacuations, and might be

Usable in further experiments or evacuation flow calculations. The evacuation speeds only apply for the specified experimental situation, which includes traversing two doors and one corner.

Situations in which hindering did occur though are just as important to an evacuation calculation, as they could also occur in a real fire emergency situation.

The arrival speeds in hospitals show that fifty percent of the outcomes lie in a range of 1.71 to 2.34 metres per second with peak values from 0.9 to 2.85 metres per second due to hindering or other disproportional walking speeds.

A good range to define the arrival speed during emergency situations probably lies between 1.9 to 2.3 meters per second, because it is expected that during an emergency situation people tend to run faster than they did in the experiments that resulted in the slowest arrival speeds.

The total evacuation times, though not mutually comparable, were in all hospitals longer than 30 seconds per bed. Indicating that it would always take at least 2minutes to evacuate a room with 2 people evacuating four beds, moved outside the fire compartment.
CFD simulations have conducted to analyse the spread of fire and smoke, and for used to determine whether a safe evacuation from the room in which the fire occurs would be possible. It shows that an arrival time of more than approximately 3 minutes will most probably result in a very critical situation (and possibly casualties). Shortening the arrival time is thus crucial.

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