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EVACUATION FROM A SINGLE FAMILY HOUSE

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ABSTRACT

The available safe escape time and the required safe escape time (ASET/RSET) were calculated for the occupants evacuation of a single-family house in the case of a basement fire. The paper summarizes the different factors and occupant characteristics of importance to consider in such an evacuation. The estimated evacuation time required for the best-case scenario and worst-case scenario are detailed. The available safe escape time was calculated for a basement fire with different floor assemblies through full-scale experiments in a test house. Measurements of smoke alarm activation, smoke obscuration density, toxicity and structural integrity were taken. Results show the very short time available for egress of about 2 ½ min before untenable conditions were reached. Interconnected smoke alarms and a closed-door between the basement and the 1st floor are recommended as well as public education to ensure a fast evacuation of the occupants.

INTRODUCTION

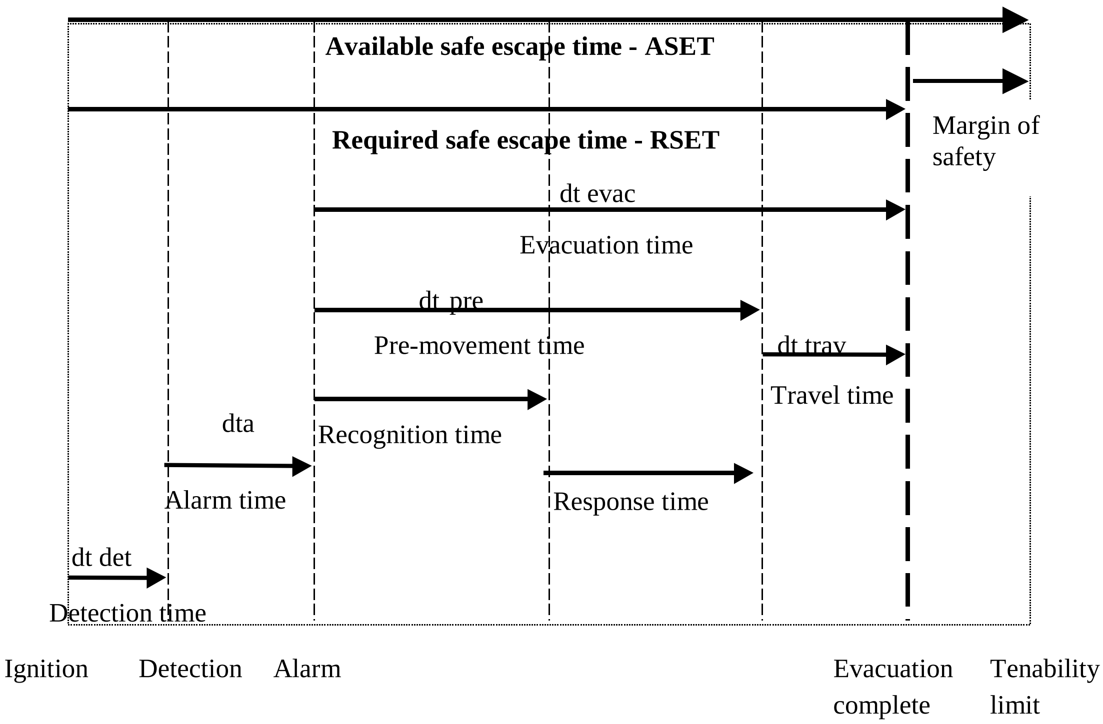
Factors that affect evacuation from typical Canadian single-family houses in the event of a fire were investigated. Egress time is found to depend on the location, cause and time of the fire, the characteristics of the occupants, the building design and the existence and location of a working smoke alarm in the house.

In Canada, over the last 10 years, approximately 40% of all fires reported were in residential buildings. Distressingly, residential buildings accounted for more then 80% of the fire fatalities and 70% of the fire injuries[1]. Similar data were found in 2007 for the USA with home fires causing 84% of fire deaths and 77% of the injuries[2]. Needless to say, if we want to reduce the overall death toll, substantial work should be devoted to better understand the residential fire problem, improving codes and standards and considerable effort needs to be invested in fire prevention and fire safety.

The statistics show that the most frequent fatal residential fire scenario occurs when a match or a cigarette, carelessly discarded just prior to sleep, ignites a fire in the living or sleeping area after smouldering for some time. If the fire starts in the sleeping room, this enclosure can rapidly become untenable preventing egress of the occupants from that room. Alternatively, if the fire starts in a living area that is far enough removed from the sleeping area, the fire can progress significantly before being noticed, blocking escape routes, leaving a narrow window of time for safe egress.

There are currently limited egress models that can be used to define and assess the timing of the evacuation process of a single-family house. In performance-based assessment, the evacuation time is often calculated using the ASET/RSET approach illustrated in the Egress Time Model presented in Figure 1. The ASET is the available safe escape time calculated from the time of ignition of a fire until the time at which tenability criteria are exceeded in the means of egress. The RSET is the required safe escape time, which is the time calculated from ignition until occupants can reach an area of safety. The difficulty of this approach resides in calculating the time to accomplish each phase of the evacuation process. The timing of each phase is dependent on a wide range of factors including fire location, combustibles in place, detector placement, space layout, characteristics of the occupants, etc.

Figure 1. Egress Time Model



The Egress Time Model is simply a model and, as such, it is an abstraction that discards details through simplification in favour of explanatory power. The strength of the model is to illustrate the importance of each phase of the evacuation process and to contrast the timing of these phases with the fire development timing. It is important to mention, however, that the ASET/RSET approach cannot account for some fire scenarios[3]. For instance, occupants who are intimate with fire ignition such that they ignite their own clothing or bedding might have no time to escape so their ASET is virtually nonexistent. Another scenario considers an occupant alone with disabilities or incapable of action, who might have an unlimited RSET, as this person cannot evacuate unaided. These scenarios are not considered in this analysis.

The objective of the study conducted was to identify timing for each phase of the ASET/RSET model for a night time winter fire starting in the basement of a 2-storey single-family house. The ASET was calculated for different floor assemblies for the 1st floor during full-scale experiments. The RSET phases were estimated using statistics, research, and expert judgment.

LOCATION AND CAUSE OF A FIRE

The location of ignition is a factor of importance in a fire. Depending on its location, a fire may burn for several minutes before being detected without significantly affecting egress routes, or may very quickly render a normal means of egress unusable. In North America, residential fires occur most commonly in the cooking area between 4 and 8 PM[4], when dinner is being prepared. Not surprisingly, cooking equipment is the main source of ignition and the first item ignited is, most often, cooking oil. Cooking fires represented the highest proportion of residential fires in Ontario leading to 12% of fire fatalities and 43% of fire injuries[5]. This relatively low fatality rate contrasts with the high injury rate. They are attributed, in many cases, to occupants being awake and active at the time of the cooking fire onset, and thus making them more likely to attempt to fight the fire or to escape.

Far more fatal are fires caused by an open flame and smokers' articles. In Ontario, although these fires account for only 14% of all residential fires, they lead to 22% of fire fatalities[5]. Lit smokers' materials, such as cigarettes and pipes, are associated with 28% of fires starting in living areas; 27% of fires starting in bedrooms; 10% of fires starting on porches/balconies; 6% of fires starting in trash; and 5% of fires starting in kitchens. These fires take place at all times of the day: 38% are at night, 35% are during the evening and 27% during the day. The first items ignited by lit smokers' materials are: 24% upholstery, 21% bedding, 16% trash and 7% cardboard or paper.

In the scenario of a cigarette or a candle igniting bedding or a mattress fire, smoke can very quickly render the sleeping area untenable, as well as cause severe burns to a sleeping victim. If the door to the bedroom is open, the adjacent corridor and rooms could become untenable and the fire might quickly spread outside the room of origin blocking egress for the other occupants. If the bedroom is located in the basement, the stairway, which is the main means of egress, can rapidly become blocked.

The scenario of upholstered furniture igniting in the living area could take place on any floor of a house. A living area could be defined as a living room, a family room, a home-cinema room or a playroom; such rooms can be located in the basement or on the 1st or 2nd floor of a house. In many houses, occupants must pass through a living area to reach an outdoor exit, which could limit the possibility of egress.

Although basement fires are not the most common fires, they pose a great challenge to the structural integrity of the floor on the 1st storey, which is also the means of egress for the occupants. Further, the fire itself poses a threat with smoke, heat and combustion products that can travel from the basement to the upper floors of the house.

CHARACTERISTICS OF THE OCCUPANTS

In order to estimate the required egress time from a house, it is necessary to identify the occupant characteristics that will impact the person's perception of danger, response, and movement to safety. Several occupant characteristics are found to be risk factors during a residential fire.

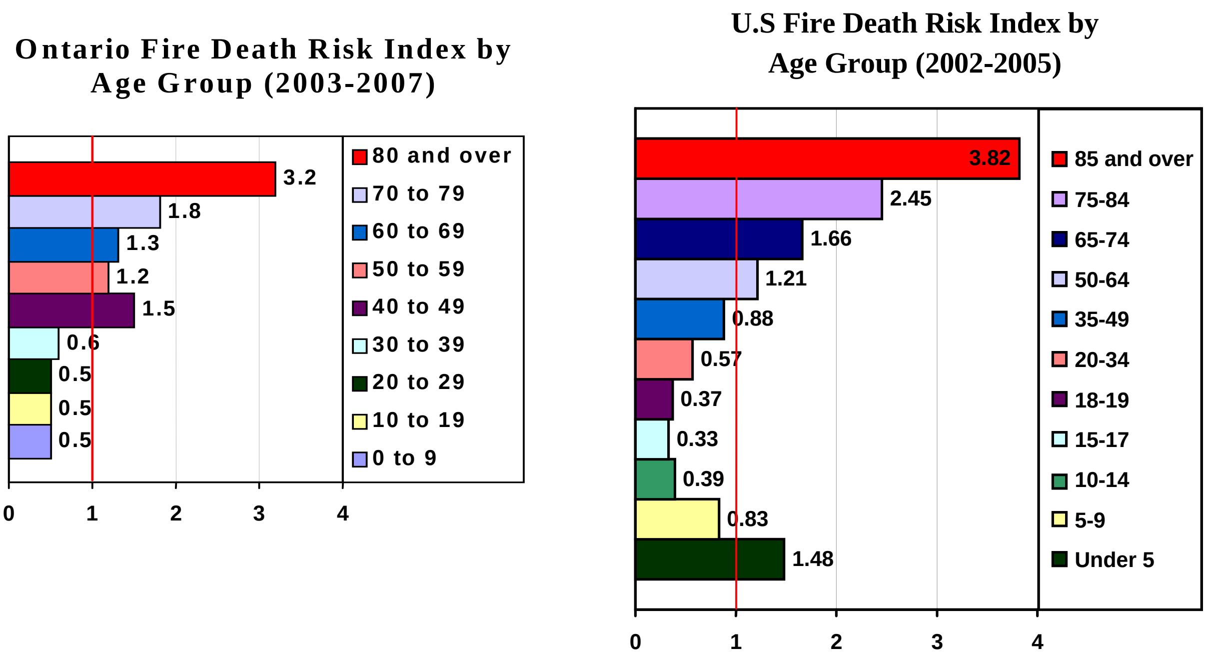
Age

Occupant's age is a very important variable in determining fire risk factors. Although there are no Canadian statistics, Ontario publishes detailed data and analysis on victims' ages relative to the provincial population. A risk index higher than 1.00 for a specific age group means that this age group is at higher risk of death than the general population of that age group. Figure 2 shows that, relative to the overall population of Ontario, people over 40 years of age, have a higher risk of perishing in a fire. For people aged 80 and older, this risk is over 3 times higher then their representation in the population.

The situation is somewhat similar in the USA although the age classes are different and the statistics available are for different years (see Figure 2). According to NFPA, states with the highest fire death rates tend to have higher percentages of people living in poverty, lower education, being black or native American, smokers and living in rural areas. Risk of fire deaths increases with age as people in all age groups over 50 have a risk index greater than 1. Particularly dramatic is the risk of elderly people aged 75 and over. A particularity of the USA statistics is the high risk of children under 5 years old. This high risk may be due to an inability to escape for children who cannot yet walk or open doors, have difficulty understanding the situation and judging the danger, as well as difficulty to awaken to an alarm due to the sleep pattern of children. However, the Ontario statistics and some other studies suggest no increased risk of fatality for young children, which might be explained by the age grouping of the data[9]. It is also proposed that although young children alone may be a high-risk group, the typical presence of at least one adult in the house to aid in arousal and evacuation is a balancing factor.

The fact that older people are over-represented among residential fire fatalities has been observed in other industrialized countries. In one Australian study, conducted between 1990 and 1995, victims 65 years of age or older, which represented 5% of the population, made up 41% of the fire fatalities. The elderly are most at risk due to a combination of factors: reduced mobility, agility and dexterity, which lengthens egress time. Further, senescence can affect the memory and increase the likelihood of dangerous behaviour, such as leaving the stove on or forgetting about a burning cigarette.

Figure 2. Ontario Fire Death Risk Index for Age, 2003-2007[5] and
USA Fire Death Risk Index for Age, 2002-2005[6]



Often related to age is the variable of disability and limitations. In the 2006 Canadian census, one out of every seven in the population reported having a disability; this represents 14.3% of the population residing in a private household[7]. Problems related to pain, mobility and agility affected the largest number of people who reported a disability. Mobility disabilities were present in less than 2% of people aged 15 to 24 but affected 44% of people aged 75 and over. The other most prevalent disabilities were hearing and learning limitations.

Sleep Stage

Being asleep, under medication or intoxicated are circumstances that limit the capacity of occupants to perceive and understand the situation and take rapid actions. Since occupants are particularly vulnerable when asleep, it is assumed that night time fires are more likely to pose a threat: statistics tend to confirm this assumption. If occupants must be aroused from sleep in a fire situation, their threshold of arousal will vary with sleep stage. The stages of sleep are numbered 1 through 4 and generally occur in cycles throughout the night, beginning with Stage 1, progressing through each stage to Stage 4, and then back through each stage to Stage 1. REM is a further stage of sleep in which dreams take place, that has an arousal threshold similar to Stage 2. Several cycles of sleep stage 1 to 4 will occur per night. Stage 4 marks a person's deepest sleep, when awakening is most difficult. The literature suggests that during the first half of the night or the first 4 hours of sleep, more time is spent in "deep sleep" Stages 3 and 4. This corresponds to an increase in fatalities during the first half of the night shown by fire statistics[8]. The second half of the night consists of Stage 2 and REM sleep, during which subjects can be more easily aroused.

The proportion and timing of sleep stages depends strongly on the age of the subject. Children tend to spend more time in Stage 3 and 4 sleep, while subjects over the age of 50 spend very little time in these stages, and tend to wake frequently during a typical night[9]. Additionally, awakening thresholds in a given sleep stage tend to drop off with increasing age. The literature suggests that, in general, children aged 12 and under will have difficulty awakening to an alarm signal. Teenagers are progressively more easily aroused as they age, and adults over 25 will awaken readily.

Drug and Alcohol Consumption

USA statistics show that 50% of the population has used a sedative or tranquilizer at some point, and that 20% use these sleeping aids frequently. In Australia, old age pensioners, though comprising only 10% of the population, consume 41% of all prescribed sleeping medication[8]. Not surprisingly, those under the influence of sleep aids tend to have higher awakening thresholds. In a study conducted by Bruck, 50% of those ingesting a hypnotic before going to sleep failed to respond to three 60s smoke alarms at 78dBA. Comparatively, 100% of those in the placebo group responded[8].

The consumption of alcohol has been reported as the strongest independent risk factor for death in the case of a fire[10, 11]. Several studies have found that approximately 50% of all adult fire fatalities were under the influence of alcohol at the time of the fire[10]. An Australian study has shown that alcohol consumption increases arousal thresholds. Three different alarm signals – the current Australian fire alarm signal, the T3 signal used in the USA, and an actor's voice – were presented to subjects who had consumed no alcohol, subjects who had a blood-alcohol content (BAC) of .05, and those who had a BAC of .08. Arousal thresholds of those with a .05 BAC showed an increase of approximately 15dBA over those who had consumed no alcohol. Those with a BAC of .08 showed a further increase of approximately 5dBA over those with a BAC of .05. Many of the subjects with a .05 BAC reported, "feeling only slightly tipsy" at bedtime, indicating that even moderate alcohol consumption can have a significant effect on arousal[12]. Overall, alcohol consumption greatly increases the risk of initiating a fire by impairing the judgment and coordination of the person. Intoxication also acutely diminishes a person's ability to notice the smell of smoke or to hear the sound of a smoke alarm. Escape from a fire can be hampered by the loss of motor coordination and mental clarity caused by alcohol.

Another occupant characteristic in family-owned residences is group dynamics, which may have a substantial impact on egress times. Families show significant reluctance to separate, and will often gather and evacuate together, through the same route. Such affiliation takes time, particularly when the fire location divides family members. This inclination can also provoke re-entry to an untenable environment when it is discovered that a family member has not escaped. The need to warn others and gather to leave as a group will often add time to the pre-movement phase of the evacuation.

There are several other occupant characteristics that could have an impact on egress time such as number and density of occupants in the house at the time of the fire. For discussion of these additional occupants' characteristics, the SFPE Engineering Guide on Human Behavior in Fire should be consulted[13].

BUILDING DESIGN AND FIRE SAFETY FEATURES

In Canada, typically, single-family houses have a full basement of 2.4 m in height. This basement usually contains the furnace, hot water tank, electrical panel, storage space and oftentimes some partially or completely finished rooms. Many houses have in the basement a family room, home office, bedrooms, laundry room and washroom.

In the 50s, the trend was to build bungalows or ranch houses of 80 m^2 over one storey with a basement; nowadays, single family houses are more likely to be 2-storey over 200 m^2 plus a finished basement[14].

Many recent constructions have what is called an “open concept” which implies that the living area is open onto the dining room and possibly to the kitchen and the stairways leading to the basement and the 2nd floor. This openness is much appreciated in North America if we look at the designs offered for new houses by the major contractors[15]. In terms of fire safety, the open concept could allow occupants to notice a fire rapidly since they can see a wide expanse of their house at once. However, the open concept also implies that smoke and fire can travel easily and rapidly throughout the house, blocking means of egress and potentially preventing occupants’ safe egress.

During a house fire, if the front or back doors are not accessible, egress could take place from a window. However, this is an unusual way out that is rarely considered, particularly for the elderly and children or generally in the winter time when windows might be more difficult to open due to ice or snow. In a 2-storey house, the sleeping area is often directly above a living area. In such layouts, a fire can very quickly fill the stairway with smoke, reducing the potential for egress.

Before occupants can begin to take action in a fire situation, they must first be alerted to the presence of a fire. The most reliable means to alert occupants, especially during sleep, is through the fire alarm signal.

Smoke Alarm

The National Building Code of Canada requires that all houses constructed since 1995 have a hardwired system of smoke alarms consisting of at least one detector per floor. These devices must be interconnected in such a way that the activation of any one smoke alarm causes every device to go off, and must produce an auditory signal of intensity no less than 75dBA in every bedroom and no greater than 110dBA in any occupied area. Since these requirements were only established relatively recently, there are a large number of houses without such an interconnected system. Unless wired to the house’s power supply, smoke alarms depend on batteries to operate. A survey of households conducted on behalf of the Canada Safety Council in 1996 reported that 95% of Canadian homes had smoke alarms, however, it is suspected that many of these smoke alarms may be not operational due to exhausted or missing batteries.

In 2002, the National Research Council of Canada (NRC) conducted a series of full-scale fire detection experiments in Kemano, a deserted town in Northern British Columbia[16]. The objective of the Kemano project was to evaluate the performance of current smoke alarms in existing houses. The smoke alarms tested were ionization, photoelectric and combination detectors powered by batteries. For the experiments, the fires were covered with a perforated metal bucket to control the amount of air for combustion; consequently the fires were small, grew slowly and had a limited oxygen supply providing the greatest challenge for the detection. The findings of the Kemano project demonstrated that the smoke alarms installed in the room of fire origin took an average of approximately 5 min to detect the smouldering fire and 10 min to detect a fire from an adjacent room. It is important to stress that the Kemano tests simulated worst-case scenarios for the smoke alarms activation.

The sound of the smoke alarm must be loud enough to reliably wake occupants. The question is, “How loud is loud enough?” Unfortunately, there is no simple answer. Current smoke alarms have an average intensity rating of 85dBA, measured at the detector[17]. Most studies agree that this is sufficient to wake a normal, middle-aged adult within one minute[8]. Unfortunately, there are some exceptions, such as most children and some teenagers who will not awake at all to this sound level[18,19]. Further, the current smoke alarms may not arouse elderly occupants and people under the influence of alcohol, drugs, or sleeping medication[8]. Increasing the sound intensity of smoke alarms is not the solution. Recent studies have demonstrated that the T3 signal or more precisely a 520 Hz square wave signal is much more efficient then a standard beeping tone in waking sleeping occupants of different ages as well as occupants under a variety of conditions[20].

Occupants can become aware of a fire by other cues then the smoke alarm signal such as perceiving smoke or heat. For sleeping occupants, however, it must be noted that by the time sufficient quantity of smoke, fire noise or light from the fire itself reach a sleeping occupant, it would often be too late for safe egress; hardwired smoke alarms are very necessary to ensure a rapid warning.

PRE-MOVEMENT TIME

The pre-movement time, which comprises the recognition time and the response time in the Egress Time Model (see Figure 1) is very difficult to estimate. Although it is possible to list a variety of factors and possible actions that could be taken by occupants during a house fire, the frequency of occurrence of these behaviours and the time invested in these actions are not readily available. This section provides timing for a best-case and a worst-case scenario for the pre-movement activities. The time estimated follows findings of the studies and statistics detailed previously, as well as expert judgement. In this analysis, it is assumed that the house fire starts in the basement during a winter night and the hardwired smoke alarms positioned on each floor of the house are activated.

Although training in fire safety and having an evacuation plan in place may aid in speeding egress, it is unlikely that the time taken to assess the situation can be totally eliminated. In estimating the pre-movement time for a best-case scenario it is possible to expect a quick recognition and response time without any other actions. It is probably fair to estimate a pre-movement time of 30s, this time being invested essentially in a quick investigation and assessment of the situation. Assuming the person is awake at the time of the fire and alone in the house, this estimate appears realistic.

The pre-movement time for a worst-case scenario is far more complex to estimate. Table 1 lists the most common activities that can take place during the recognition and response phases. The time taken to awaken an occupant for a worst-case scenario is estimated at 120s assuming that most occupants will awake during this timeframe. The time to investigate the situation is set at 60s for a worst-case scenario. The activity of fire fighting, which is recurrent in case studies of residential fires, is estimated at 180s. There have been limited statistical studies performed on the effects of winter temperatures on egress time. A comparison of pre-movement time during fire drills conducted in summer and winter conditions suggests that occupants require approximately two and a half minutes more to prepare during the winter[21]. In light of these findings, it is suggested to use 150s to dress for winter condition for the worst-case scenario. Gathering belongings is also commonly reported as a pre-evacuation activity; in the worst-case scenario 30s is allocated to this activity.

Table 1. Pre-movement Activity Time Estimates in Seconds

Activity	Best-Case	Worst-Case
Awake to fire alarm	-	120s
Investigate situation	30s	60s
Fight fire	-	180s
Gather family member (s)	-	60s
Dress for winter conditions	-	150s
Gather belongings	-	30s
Total Pre-movement	**30s**	**600s**

The actions listed in Table 2 may or may not take place during a house fire and the time allocated to each action for a worst-case scenario is open for discussion. This overall pre-movement time for the worst-case scenario of 10 min may appear relatively long and its probability of occurrence might be fairly low. At this time it is not possible, with the limited data available, to provide more precise estimates.

TRAVEL TIME

Once occupants have decided to evacuate, the next stage of egress is deciding which route should be used to leave the premises. Most of the research in wayfinding is devoted towards the reactions of people in public buildings; in their own homes, it is assumed that people will be familiar with the potential means of egress. Even so, occupants may not choose the closest or safest means of egress. Research has shown that the escape routes chosen most frequently are those that are most often used by the subject on a daily basis, such as the front door. It is also noted that the elderly population is especially unlikely to make use of windows in egress[22]. Of additional concern are possible egress routes from basements. Often, the only accessible means of egress is through the main stairway, to a ground floor exit. Should the main stairway be blocked by fire or smoke, alternate egress through elevated small windows may be difficult or impossible.

The travel time required to actually evacuate a normal-sized Canadian residence is trivial compared to the pre-movement time. One survey, conducted among the NRC-Fire Research group staff, attempted to more closely estimate wintertime evacuation from single-family houses. Using a stopwatch, participants measured how long it took them to travel from a laying position on their bed to their normal exit, put on their coats and boots and evacuate. The mean distance travelled during these evacuations was 16.6 m, and the mean time reported was 47s; this is an average evacuation speed of 0.4 m/s, which included time to get dressed for winter conditions[23].

REQUIRED SAFE EGRESS TIME (RSET)

From these results outlined in previous sections, a range of times for each phase of the Egress Time Model is presented in Table 2. These times represent a best-case and a worst-case scenario, to establish the bounding range of RSET values.

Table 2. Estimated Required Safe Egress Times for a Single Family House

Phase	**Best-Case**	**Worst-Case**
Detection Time	60s	300s
Alarm Time	0s	10s
Pre Movement Time	30s	600s
Travel Time	30s	60s
Total RSET	**120s**	**970s**

It is suggested from the Kemano study reported previously to use 5 min as an upper limit for the detection time since the Kemano tests pertain to worst-case scenarios of rare occurrence[16]. Further, an additional time of 10s is added for alarm time activation for the worst-case scenario. In fact, detection and alarm activation may occur much more quickly in an actual fire situation under different conditions, so a best-case scenario is judged at 60s for detection time with instantaneous alarm time activation.

The pre-movement times detailed in Table 1 are reported here as 30s for best-case and 600s for worst-case scenarios. The range of reported travel time values from the NRC survey indicates that it should take between 30s and 60s of travel time to evacuate a 2-storey house. The National Institute of Standards and Technology (NIST) calculated similar values of 35 and 60s for movement time in a similar house[24]. The values found in the NRC survey of 30 and 60s are used respectively as a lower and an upper limit for travel time.

According to the time estimated in Table 2, the RSET from a single-family house could vary from 120s to 970s (2 min to 16 min 10s). This represents the time from fire ignition to the time the occupant has reached a place of safety outside the house. The estimated Evacuation Time (the addition of the pre-movement and travel times) is 1 min for the best-case scenario and 11 min for the worst-case scenario. These calculated evacuation times represent reasonable lower and upper bounds according to the information currently available.

Given the broad range of evacuation times that can result from such analysis, it is clear that, depending on the specific circumstances of the fire, the building design and the occupant characteristics, a distribution of times can be expected. It is possible that the distribution of evacuation times is positively skewed, suggesting that the probability of short evacuation times resembling the best-case scenario might be more likely than times close to the worst-case scenario presented in Table 2. However, there is not enough data in the literature to develop a probabilistic analysis.

FULL-SCALE BASEMENT FIRE TESTS

A series of full-scale basement fire tests was conducted at NRC looking at the structural integrity of engineered floor systems that could be found between the basement and the 1st floor of a single family house[25]. As seen in Figure 3, a test house was built comprised of a basement, a 1st and 2nd storey with a floor area of 95 m^2 and ceiling height of 2.4 m. The floor systems tested were wood I-joist, steel C-joist, metal plate and metal web wood truss as well as solid wood joist assemblies. A single layer of oriented strandboard (OSB) was used as the floor over the tested assemblies without any additional finishing material such as carpet, hardwood or vinyl flooring. The 1st floor test assembly was loaded with concrete blocks to represent a load of 0.95 kPa. On the basement side, the ceiling was the assembly without any protection. These conditions met the minimum code requirements.

Figure 3. Test Facility under Construction and Fuel Package Mock-up Sofa

A fuel package representing a sofa fire was developed to create a repeatable fire in the basement. The first item ignited was polyurethane foam which ignited a wood crib, see Figure 3. This produced a relatively severe, fast-growing fire generating CO and CO_2 in a vitiated oxygen environment. The floor assemblies were tested under two conditions: with the basement door open or closed.

Tenability analysis was conducted using temperature, concentration of combustion products as well as smoke obscuration densities (OD). Since susceptibility to toxic and asphyxiant gases varies in the population, the tenability analysis used a fractional effective dose (FED) of 1 for healthy adults and 0.3 for more susceptible persons. The tenability analysis combined with the structural integrity measurements provided the time available for occupants' safe egress or ASET.

In all tests where the basement door was open, the first hazard observed was the smoke obscuration density obtained consistently at around 180s after fire ignition (see Table 3). Although smoke obscuration would not directly cause incapacitation, it could considerably impede evacuation, disorienting and slowing down occupants, which would prolong exposure to other hazards. The incapacitation conditions due to heat or toxic gases were reached 20-50s after smoke obscuration on the 1st floor and 20-65s later on the 2nd floor for healthy adults, FED=1. The difference for incapacitation time for healthy adults FED=1 and more susceptible persons FED=0.3, was never more then 35s. In the open basement door scenario for all the tests, the floor assembly failure took place after the inside of the house had reached untenable conditions. Thus, it is not the structural failure of the 1st floor that would jeopardize occupants' egress but the heat and toxic gases; still, it is interesting to note that the failure time was 35-60% faster for the engineered assemblies compared to the solid wood joist assembly.

Table 3. Sequence of Events, Time in Seconds

Floor Assembly Type	First Alarm	OD = 2 m^{-1}	1st storey		2nd storey		Structural Failure
			FED=0.3	FED=1	FED=0.3	FED=1	
Test with door opened							
Solid wood joist	40	185	205	235	225	255	740
Wood I-joist A	48	183	205	213	225	247	490
Wood I-joist B-1	45	170	198	211	208	241	382
Wood I-joist B-2	38	161	198	199	207	241	382
Wood I-joist B-3	43	184	203	216	218	248	414
Steel C-joist	30	195	207	215	245	280	462
Metal-plate wood truss	40	190	206	232	235	260	469
Metal web wood truss	40	170	192	207	230	255	325
Test with door closed							
Solid wood joist	42	297	466	676	362	501	1200
Wood I-joist A	44	319	329	484	364	504	778
Metal web wood truss	50	360	400	486	375	510	474

The same tests conducted on three assemblies with the basement door closed provided a completely different picture (see Table 3). The rate of fire growth was reduced as well as the movement of combustion products from the basement to the upper floors. The closed door prolonged the time to reach untenable condition as well as structural failure, except in the metal web wood truss condition. Overall, the closed basement door more then doubled the available time for egress.

AVAILABLE SAFE EGRESS TIME

In all tests, the smoke alarm located in the basement activated 30 to 50s after fire ignition. Assuming that the smoke alarm is hard wired and issues a signal simultaneously on each floor of the house, in the worst-case scenario, with the basement door opened, occupants in the 2nd floor bedroom would have 2 min to escape before smoke obscuration and 2½ min until untenable conditions on the 1st floor. With the basement door closed, the time before smoke obscuration is over 4 min and untenable conditions on the 1st floor are reached at around 7 min for healthy adults.

CONCLUSION

Currently, it is only possible to provide rough estimates of residential egress time, which should be used with great care. The research findings outlined in this paper show a wide variability in egress data dependent on several factors including age, alarm signal, fire fighting activity and group dynamic. From these results, a required safe egress time (RSET) of 2 min for a best-case scenario and 16 min 10 s for a worst-case scenario, from fire ignition to the time the occupant has reached a place of safety outside a typical 2-storey house seems reasonable from what is known at the moment. The variability in these figures is vast and largely dependent on characteristics of the individual, the building design and the fire scenario. More research is needed on the topic of single-family house egress time in fire situations to confidently calculate the required egress time. Appropriate investigations would ideally include full evacuation drills of single family houses in winter conditions, using a sample population of varied age while informing as few members of the household as possible of the nature of the exercise. Conducting such tests raises considerable ethical issues and would probably prove to be difficult to carry out using realistic scenarios. Actual residential fires should be investigated by interviewing survivors in an attempt to determine the time spent doing different activities from the moment of notification to the time of reaching safety. The combination of these two research strategies, drills and case studies, would help populate the egress time model with estimated times that would eventually provide more precise predictions.

A recent study performed by NIST suggests that the ASET for a single-family house equipped with smoke alarms, which used to be estimated at 17 min, may only be 3 min for ultra-fast fires involving upholstery furniture. While some of this difference in ASET times compared to the NRC study may be attributed to the tenability criteria used, it is clear that the rate of fire growth in current tests is significantly faster than those found in tests conducted in the 70s[24]. This result is troublesome, as it may mean that the ASET falls below the calculated RSET for many escape scenarios in single-family houses.

The results of the NRC study show that the structural failure of the floor assemblies in the fire tests did not appear to be the critical factor affecting occupant life safety since the tenability limits were reached first. Results demonstrate the importance of the hardwired smoke alarm positioned on every floor of a house as well as the potential benefit of a closed door between the basement and the 1st floor of a house. Public education is a must, as all studies confirm the limited time available for safe egress in a house fire.

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