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A conceptual approach using risk as a basis of building performance design

by Assoc. Prof. Brian Meacham, Fire Protection Engineering, Worcester Polytechnic Institute, MA, USA

> *The risks to which society is, in fact, exposed are largely determined by regulations and how effectively they are implemented and enforced. Regulations decide which facilities are constructed where, and how they must be designed, and under what conditions they will be operated (Otway, 1985).*

Considered in this light, building regulations are a primary risk management tool used by government to protect the health, safety and welfare of its citizens. In many countries building regulations were originally enacted to help prevent conflagrations that could burn down large portions of cities. The Great Fire of London in 1666 is often pointed to as the event that triggered regulated fire separation requirements. Likewise, illnesses resulting from poor sanitation led to regulatory requirements for sanitary environments.

Over time, building regulations evolved as a mechanism to ensure that buildings were suitably designed and constructed to minimize the risk to occupants from natural, technological and health hazards, while minimising their risk of collapse due to poor design or construction. In developed countries, building regulations have been highly successful in this regard.

In general, building regulations manage risk by describing performance expectations under a wide range of conditions, including structural performance under load, fire safety, adequacy of indoor environment and sanitary conditions. Some countries, such as the USA, try to stipulate most of the requirements that buildings are expected to achieve through detailed prescriptive measures. While this can work for a wide range of 'typical' building configurations and uses, it results in regulations that are several hundreds of pages in length, and for which variances or exceptions are sought for nearly all large, complex and/or unique buildings. It is often unclear what levels of safety are actually being achieved: the system is only tested when failure occurs.

In other countries, a more performance-based approach has been taken whereby the functional objectives are legislated but not the specifics of how they should be met. This approach has been considered successful in facilitating innovation but the length of time and uncertainty evident in the approval process, and the potential for differing levels of performance have led in some counties to attempts to better quantify and legislate for levels of risk or safety acceptable to society.

Since the term 'risk acceptability' can vary according to the perspective of stakeholders, research over the past few decades has provided policymakers some insight into the problem by combining analytical data with risk management solutions and mitigation measures agreed upon by the various stakeholders. This process can include a review of how regulations and other risk management mechanisms have been used to reduce risk to date or by estimating the risk exposure that remains after the mandating of certain suggested mitigation measures.

Given the way that most building regulations are currently developed and implemented, however, there is not a clear sense of whether risks are being managed appropriately across the range of hazards or if there exists a wide disparity between exposure, mitigation measures and associated costs. There are many reasons for this. First, for all of their risk reduction benefit, buildings (and building regulation) cannot protect all occupants from all risks. It is impossible to control for all potential hazards and allow buildings to still be used in a manner suitable to the occupants. For example, we want our buildings heated, we want them to be energy efficient, and we want to be able to cook food. However, heating and cooking appliances create potential ignition hazards, and thermal insulation installed for energy efficiency can be combustible. Also, we use stairs to move between floors, but they pose tripping hazards. We rely on the building structural system to protect against most natural hazard events, but it is difficult to cost-effectively design all buildings to withstand the largest cyclones, earthquakes or floods.

In this issue

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We understand there is a balance between how much money we choose to invest to reduce risk, the potential consequences and how likely those consequences are. We understand there are limits to technological solutions. We accept that unwanted events can still occur despite regulatory solutions, because we cannot control the hazard or who is exposed. Market-based measures, such as insurance, further manage the risk, in some cases providing lower premiums if sprinklers are installed, for example.

A real shortcoming is that we do not know if the level of risk managed via building regulation, and the supporting regulatory infrastructure, is appropriate. This is because the components of building regulation are not integrated in a holistic manner, and there is no common set of risk or safety levels underpinning the building performance requirements. Using the USA by way of example, in 2013 there were 30,208 deaths due to unintentional falls, and 2,818 deaths due to unintentional fire/flames/burns. A large majority of these deaths occurred in the home. However, if one looks at where money is spent, a significant amount is spent on fire protection in commercial and public buildings, and little on fire protection or protection from falls in the home. We also spend a considerable amount on seismic protection, including seismic retrofit of buildings, again in the commercial and public building sector, while damage to homes from tornados and other high-wind events attract much less attention.

While there may always be some disparity between the risks people face in buildings, and in how building regulations are developed and implemented to mitigate risk, it would be helpful to have a single risk metric against which to benchmark the broadly tolerable level of risk and the amount of resource society is willing to commit to manage that risk. As a starting point, it is suggested that the benchmark be the annualized fatality rates from all sources with a given society. The level of risk to be managed via building regulation can be selected as a percentage of this rate.

This approach is suggested for several reasons. First, it can be very difficult to select a specific target risk-to-life value for regulation. This is done in some regulated areas, such as the siting of hazardous facilities, but it has proven more difficult generally for buildings, as politicians and certain stakeholders, such as the fire services, find it hard to publicly state that they accept any risk of death, even though that risk manifestly exists. Second, there is a lack of key data for some hazards, such as the probability or frequency of fire ignitions in buildings, or the probability of seismic shaking intensity at a specific location. By starting with the fact that all people die; that statistics provide insight as to who is most at risk, and setting a target for the contribution to additional fatality risk from the built environment, some of the political difficulties may be avoided, as well as some of the technical challenges.

To first order, it is suggested that the contribution of risk imposed by those features of new construction, which fall under the bounds of building regulation, shall contribute no more than 1% of the age-specific risk of death that people face and no more than 1% of the risk society faces as reflected in frequency-number (F-N) curves associated with past or potential large-area impact events. For existing buildings, the target would be that risks associated with buildings contribute no more than 10% of the background risk.

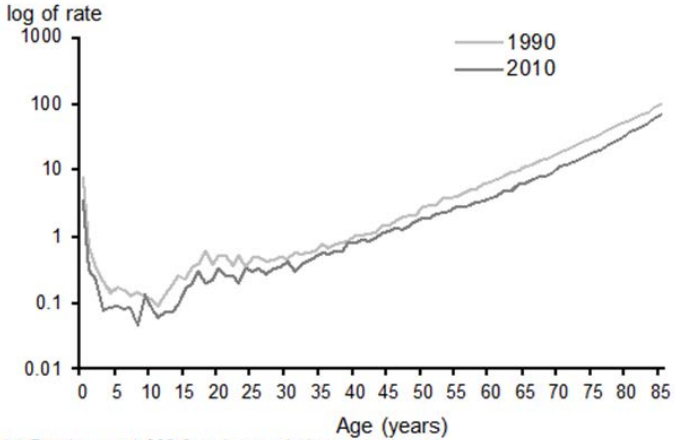
[F-N curves usually plot the number of fatalities (N) on the abscissa against the annual exceedance probability (F) on the ordinate axis usually on a log-log grid.]

So, where did these values come from? The 1% and 10% of background risk targets were inspired by a Dutch approach to tolerable risk targets for populations around the proposed site of a new hazardous facility. In 1988, a law was passed in which the tolerability limit for individual risk due to process industry hazards was set at 10^{-6} per year. The Netherlands Ministry for Housing, Land Use Planning and Environment took the approach that since life expectancy in the Netherlands is highest for 14-year-old children, at a minimum death rate of 10^{-4} per year, exposure to a hazardous activity should be limited to only 1% of the already existing probability to die that year (10^{-6}) (Pasman and Vrijling, 2003). It was further determined that the risk to those around an existing facility should be limited to 10% of the already existing probability to die that year (10^{-5}).

These targets seem reasonable. In the USA there were about 2,600,000 recorded deaths in 2013. Most are associated with health-related issues or natural causes, with accidental deaths about 30,000 from falls and 3,000 from fires. This is about 1.25% of the deaths. Since not all deaths due to falls or fires occur in or are associated with buildings, the actual number could be closer to 1%. More detailed analysis is needed, and consideration should be given to illnesses that could be related to buildings (e.g., from mould, lack of heating or cooling, structural failure due to earthquake or wind, or cuts resulting from impacts with glazing systems, etc.), but the order of magnitude appears about right.

Unlike the Dutch approach, however, it is suggested here that the 1% and 10% targets be considered relative to the age of the population, since age is a key indicator of vulnerability. Again, it is well understood that there are a variety of factors which define vulnerable populations, but to a first approximation age seems a reasonable starting point. It also helps that there are clear regions where age and fatality rates are closely linked.

Consider the following curve from the Australian Bureau of Statistics accessed on 18 February 2016, http://www.abs.gov.au/ausstats/abs@.nsf/0/8D107FC8CC704456CA257943000CEDA6?opendocument, Figure 2.6.



(a) Deaths per 1,000 female population at each age.

This figure compares the age-specific female mortality rates in Australia for 1990 and 2010. It is noted that "following relatively high rates of death in infancy, death rates decline sharply through childhood. In 2010, people aged 5-9 years and 10-14 years had the lowest age-specific death rates (ASDRs) in Australia. ASDRs begin to increase from around 15 years of age and, for nearly all age groups, ASDRs are higher for males than for females. Age-specific death rates for males increase gradually until around age 40-44 years, where they begin to increase more quickly throughout the older age groups. Age-specific death rates for females aged 15 to 34 years are relatively low and constant. Steady increases in female ASDRs are evident beyond 30 years of age and continue throughout the older age groups. Over the past 20 years, death rates have declined overall for both males and females for all ages. The largest proportional decreases have occurred in the younger age groups." (ABS 2016).

These data illustrate that the risk of mortality varies by age. If we assume, for example, that the benchmark is a 45-year old female, the risk of death is about 1/1000, or 10^{-3} per annum. However, for a 10 year old, the risk is about 0.1/1000 individuals, or 10^{-4}: an order of magnitude lower. By contrast, for an 80-year old, the risk of death is about 100/1000, or 10^{-1}: two orders of magnitude higher than the benchmark. Overall, two of every three deaths in Australia in 2013 occurred among people aged 75 and over. These values can be considered the background individual mortality risk. It is worth noting that the shape of these curves is not unique to Australia: similar trends are generally seen in all developed countries, and follow observations first made in the 1800s (Gompertz, 1825).

Why is this important? While there are many ways to look at setting a tolerable risk criterion, including picking an average value across the population, it is not clear that such approaches provide sufficient granularity to serve as a useful benchmark. By contrast, in taking the approach of regulating for a target additional contribution of 1% above the background age-related risk, the outcome is more equitable - 1% for everyone - and the vulnerability of key population groups – in this case the very young and the very old – are taken into account.

For example, if a tolerable risk criterion of say 10^{-5} per year for risk of death due to fire in a building was set across an entire population, and the suitability of safety measures was judged on their ability to achieve that level for the entirety of the population, that would mean the risk of death from fire in a building for an 80-year old person would have to be reduced to a level that is four orders of magnitude below the risk of death by all other means. The cost to reduce the risk of death for this population group, solely through building provisions in a building code, would be significantly high, and far from optimized from a net-social benefit perspective.

It is simply not practical to reduce the risk of death to this population group so much just through building-related measures. This is why in practice we rely on human intervention as well, such as caregivers. The same can be said for infants and other at-risk groups. Building regulations, and the safety measures in buildings which result, are not currently aimed at protecting to a high level infants or the elderly; rather, it is expected that care givers will be helping these populations, and the risk mitigation levels targeted at them.

By taking an approach where the target risk contribution from a building is no more than 1% of the background risk of the target population, a better outcome is attained. For persons older than 80, the risk contributed by the building would not be expected to be more than 10^{-3}, whereas for those in the 15-45 age bracket, the building-related risk would about 10^{-5}, for infants 10^{-4} and for young children 10^{-6}. While some might say 10^{-3} for elderly is too high, it should be understood that the ability of the person to respond to alarms, to odours or to another person or to move to withstand the hazard, is already much lower than for say a 30-year-old. Thus the options become more limited and more costly. A society can choose to require measures to lower the risk, taking into account individual characteristics such as a desire to facilitate people living in their own homes longer, but such decisions should be made in balance with available resources and risk reduction measures in other areas.

Likewise, concern might be noted relative to infants. However, for infants, the primary means of risk mitigation is the caregiver. Infants cannot protect themselves from many risks; they cannot move themselves and they cannot articulate their needs. There are few features, materials or systems that can be integrated into a building that, without additional intervention of a caregiver, would significantly mitigate risk.

Currently, risk or hazard mitigation is based on protecting the caregiver, who if 'safe' can mitigate the risk to the infant, the elderly or the disabled. Moving to a risk target approach, this means that buildings in which the very young and the very old might constitute a significant percentage of the population should be designed to protect caregivers with a target of no more than 1% of the background risk. If society decides to place more people at higher risk, such as facilitating aging in place, they must either be prepared to require extra protection to lower the risk, or be prepared for the likely losses.

In a recent study of fire mortality rates in Sweden (Jonsson et al, 2015), it was found that mortality rates amongst young children has dropped significantly in recent decades. As it happens, this corresponds to the increased use of daycare for children outside of the home. In the 1960s, it is reported that only about 3% of children in the 0-5 age group were in daycare, the rest taken care of at home, but by 2014 some 84% of children in the age group spent time in some type of organized daycare outside of the home. One can review similar situations with mortality rates amongst the aged when considering those living in protected aged-care facilities (e.g., sprinkler protected) as compared with those living at home.

In considering societal risk, the situation is similar. If one were to establish a single F-N criterion line, and apply it uniformly, that would mean that some areas could be significantly over-protected, and some significantly under-protected. Consider cyclone related risk: if all buildings were to be designed such that the risk to life is benchmarked against a location where there is a high likelihood of severe cyclones, then all buildings in non-cyclone areas would have to meet the same standard. This would mean significant cost for little benefit. It is not how it is done today, and should not be adopted going forward. Rather, by looking at location-specific risks (to individual and society), and establishing targets for those areas wherein no more than 1% of the background risk is contributed by new construction and no more than 10% of the background risk is contributed by existing buildings, a more equitable and cost-effective outcome will be realized.

This approach also reflects the difference in risk-cost-benefit relationship between new and existing construction. It is generally more cost-effective to implement risk mitigation measures when designing and constructing a new building as compared to retrofitting an existing building.

The approach of benchmarking societal risk at 1% (or 10%) above background F-N criteria holds for risks to large populations in a single building, such as from fire, chemical release or explosion, as well as to large numbers of people distributed over a large area, such as for natural hazards. While the F-N curve is often thought of as an approach for an 'external event' such as earthquake or hazardous material release, is it also applicable for fire in a building in which large numbers of people are present. This is why, historically, there have been more safety measures required for places of assembly, or for tall buildings. In these cases, the risk associated with the building features should contribute no more than 1% (or 10%) of the societal risk (in terms of historical F-N representations). In this case, there is no age-related component: however, the risk will change as the occupancy changes, e.g., stadium, day care centre, high-rise building, hospital or nursing home. For buildings with more lives at risk, the cost-optimal line typically allows for more installed safety measures than when the risk is lower.

If such an approach is adopted, one can then look at the various components of risk to life as related to the built environment and make more informed decisions on risk mitigation and expenditures. As already noted, there are several areas of concern, including risks from fire, structural failure, poor indoor air quality, unhealthy temperatures and sanitation systems. If the total allowable contribution to all areas is 1% of background risk, one can then look at the contribution from each hazard towards the 1% limit and make associated regulatory and risk mitigation decisions. For example, it may well be that more focus on uniformity of stair rise and run dimensions will result in greater risk reduction at a lower cost than the installation of a particular type of fire protection measure, or that the installation of simple tie-downs for residential roof systems to prevent damage in high winds will result in more risk reduction at a lower cost than the seismic bracing in low rise office buildings. This does not mean any particular risk is more or less important than another, but is suggested to provide a common means for comparing and for mitigating those risks of most importance to society to acceptable or tolerable levels.

This article has proposed a new way of thinking about risk and performance in buildings. While much more work is needed to refine the concepts, such an approach is needed to better rationalize the performance criteria established for buildings and, by basing the performance on overall risk as contributed by the building, better performing buildings will result.

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For more information contact: bmeacham@WPI.edu

Brian is currently working with the Australian Building Code Board helping it explore some of these ideas.

A Notable Precedent in 1371

> "The sheriff was ordered to distrain on AB and others on the ground that they repair faults in the sea-walls (wallias) adjoining to their lands and if they are found not adequate, to distrain on all the tenants of those lands who have, or in some way could have, a protection, benefit, deliverance or loss by reason of the repair or non-repair of the aforesaid sea wall, in such a way that all of the aforesaid tenants, should make contribution to the aforesaid AB and others for making and repairing those sea-walls in proportion to the size of their tenure."

The recent Black Nor'Easter storm on June 2016 that affected much of the eastern seaboard highlighted once again issues concerning coastal erosion and the protection of exposed property (Risk Frontiers Newsletter October 2016). In a recent court case the following legal precedent was presented. As translated from original Latin, it suggests that those living on the coast have an obligation to protect those in the village living further away from the shoreline and that everyone in the village has an obligation to pitch in in proportion to the value of their assets and to the degree that these benefit from any such seawall. At least that's what I think it means! [Ed.]

This swimming pool at Narrabeen was supposedly built to withstand a 1 in 100 year storm. Some would say it did, as it migrated down the beach intact!

Picture credits are Australian Associated Press (AAP).