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A Parametric Fire Risk Assessment Method Supporting Performance Based Approaches – Application to Health-care Facilities in Northern Italy

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Fire risk assessment has always been a challenging issue. Furthermore, performance based approaches to fire engineering showed that risk based decisions and fire scenarios are a fundamental element of the fire safety strategy assurance. In particular, a correct assessment of the risk allows all the involved stakeholders to identify a specific strategy among a pool of possibilities. Risk assessment is the perfect tool to identify comparable fire protection strategies and to measure fire risk reduction associated to the single specific prevention and protection measures composing each different fire strategies. This approach implies the need to abandon a classic, not even conservative approach, that in many cases linked the total fire load to the fire risk level, despite specific dynamics, layouts, prevention measures and risk management issues during time. During the years, a number of different methodologies have been developed: for specific cases, for industrial or civil buildings, to adopt a method enforced by the local law and regulations acts, etc. Methods have been based on matrices, indexes, check-lists, etc. Present paper illustrates a method developed by the authors taking into account several international recognized methods; even coming back to methodologies developed in early seventies. The Method is named “FLAME” (Fire risk Assessment Method for Enterprises), it goes back to the fire safety fundamentals against a generalized approach to fire safety engineering based on complex and time-consuming methods like CFD that deals only with the ‘consequences’ aspect of the fire risk (that is indeed characterized also by frequency estimation) using as reference scheme the “Fire Safety Concept Tree” explained in detail in the NFPA 550 Standard. In order to identify the most appropriate fire safety strategy it is important to identify the associated fire risk that the strategy is intended to mitigate to a certain level. Alternative solutions can be evaluated considering the risk reduction operated by different strategies and by different elements composing the fire strategies themselves and also costs with a modern ALARP approach. A clear advantage is the possibility to get an overview of the whole fire risk as the cumulative risk assessed by the model and not solely related with the consequences evaluation of a limited number of fire scenarios (usually the most obvious ones). Risk level assessment leads to the identification of the fire scenario (or a pool of) that governs and limits the specific situation, declined for both humans and structures (assets) considering that the two vulnerabilities could be linked to different fire risk scenarios. The method has been tested against different buildings occupancies. In the present case results of the FLAME method application to hospitals and health-care facilities are reported. A fire compartment-based risk estimation has been conducted on an overall of about 300 compartments (overall size of about 60000 m^2). Coherence has been found among risk estimation by FLAME parametric code and prescriptions of the Italian fire code. There is good agreement when assessing the RSET with the method proposed in FLAME, dealing with the occupants’ behaviour and the actual characteristics of occupants in clinics or hospitals and difficulties due to poor mobility or incapacity to understand emergency cues. In general, the level of risk is identified as shown in Table 1.

1. Performance-based code: State of art

As anticipated a correct risk assessment should address both probability of occurrence and consequences on exposed humans, structures, assets, etc., identifying the specific objectives for each vulnerable targets, an acceptability threshold, the correct dynamics associated with the relevant fire scenarios that pose treats to the various targets. Lately the great advances in the computational power of computer machines led to a noticeable improvement in the field of consequences assessment. During the years a number of fire safety issues have been approached with fire dynamics simulation; nowadays personal computers are able to perform even complex calculations in a very short time. Specific simulations have been developed especially for complex environments (industry, tunnels, highrise buildings, heritage buildings, etc.). This way of proceeding moved the safety engineer to focus more on the dynamics part of the problems rather than on fire risk assessment issues. Specific advances in fire risk estimation have not been observed apart from some very specific fields of interest (e.g. nuclear, offshore, etc.). Furthermore the diffusion of a number of advanced tools nowadays available on generic personal computers moved a lot of fire engineers in facing protection approaches just with simulation (even in cases where it can be an useless effort), not taking into consideration principles of fire dynamics and combustion and the elementary principles on fire risk assessment. This perception led the authors to develop a specific method able to overcome too qualitative approaches that are completely not suitable to face nowadays challenges (posed for example by new construction materials, complex geometries filled buildings, etc.) as well as not suitable to measure risk reduction associated to different fire strategies. FLAME methodology has been then identified coming back to the key elements composing fire risk and the associated degree of those in modifying the performance. The method is indeed inspired from recent international standards (ISO 17638: 2010, PD 7974: 2004, NZ Building Code, 2013) and from literature milestone in the fire safety study (SFPE Hanbook 2008, Karlsonn & Quintiere 1999).

Table 1: Risk evaluation level for different occupancies

RISK LEVEL	Occupancies
HIGH	Hospital ward, Clinics with public access (no acoustic emergency devices installed), warehouse and archives, surgery and intensive care division
MEDIUM	Clinics with evacuation cues by messages, offices with no public access, technical plants
LOW	Connecting zones, common areas, technical offices, 24h surveyed area, technical plants (air treatment plants, water heating circuit)

The first shift from the comply/not comply strategy of fire protection towards a performance based and parametric approach dates back to ‘70s. One of the first outcomes was the Fire safety Concepts Tree (NFPA 550) a basic document to describe this systems approach to fire safety; their features comprehended:

- The concept of a relative risk
- The concept of acceptable level of risk
- Management goals in order to achieve acceptability
- An event logical tree form, letting the connection among components of the systems and their comparison of their performances;
- The use of probability to describe fire safety performance.

The two branches of the tree are represented by preventing fire factors and consequences management, their pursuing lead to the upper root of it, i.e. the “Objectives of the fire safety strategy” element, the final stage of the approach, only if these objectives are reached the safety is granted.

2. Flame inspiration and features

FLAME risk assessment method have been deeply inspired by several index based methods that describe risk using a set of predefined parameters (Gretener, FRAME, FRAMINI) originally developed to estimate fire risk level associated with existing facilities for insurance purposes. Insurances have always conducted fire risk audits using simple, efficient and parametric methods. Generally this kind of methods, in manufacturing field, where aimed to support the decision in installing a fixed fire protection sprinkler system. At the same time similar methods (Dow & Mond Index) have been employed in the oil and gas, chemical, petrochemical fields to reach an overview of the safety level associated to process units, especially in terms of explosion and fire risks. An important aspect of these approaches is the combination of both hard and soft factors, negative and positive to describe the risk level. Beside the key elements describing fire danger also fire protection (active and passive measures) can be assigned values in a predefined range and at the end specific issues related to fire safety management aspects can be evaluated against specific indexes to reduce or confirm negative performances. FLAME has been coded in the same way, with a specific feature: the differentiation among the indexes pools used for different targets (i.e. humans and assets). This allows the definition of specific fire risk values for different targets, different acceptability criteria with the subsequent evidence of the measures to be put in place to leverage the safety level. Several papers of the authors illustrated how fire risk assessment methods could be used (Marmo et al. 2009, 2012, 2013a and b, Fiorentini et al. 2016). Here detailed description of the FLAME method can be found in other publications (Fiorentini et al., 2016 & 2017) while the article deals with the results coming from the application of the method to health care facilities that are recognized being a critic occupancy due to a number of factors and, for this reason, soft factors (fire safety management) can deeply affect the assessment.

3. Application to Healthcare facilities

3.1 Risk estimation: aggregate data sets

Since early studies on fire safety for civilian buildings, healthcare facilities had posed a critical issue due to the great factors to be taken into account in fire risk investigation. These facilities are often characterized by a structural complexity. A relevant issue is also represented by the occupancy characteristic: in hospitals, a great number of people are unable to move and are dependent on staff members, occupants of some wards are connected to fixed equipment (life-support system, dialysis machines) or could be unaware of damages (elderly people, psychiatric patients, children). The third factor depends on the fire spreading capability. In those type of buildings, severe consequences could arise from the spreading of smoke, flames, or only heat effects: one of those elements could compromise or even make fire measures and management procedures in place useless.

In the planning of the fire safety system of healthcare facilities, several elements should be considered:

- Geometry and materials of escape routes;
- Diversification of room protection measures;
- Fire compartment and smoke control systems;
- Separations and shafts for technical plants passage;
- Atrium and waiting hall issues;
- Accessibility to firefighters

A safety key element is the presence of a certain type of alert system instead of another. Public Address (PA) system could provide a quick response of the occupants and grant their safe escape, while, if the fire discovery is due to people present in the fire-starting room (and no automatic smoke and heat detectors are in place) a safe escape could be compromised.

Moreover, healthcare facilities require optimal communication within and between buildings. These requirements are not always in accordance with the demands of fire safety. The presence of atrium, waiting halls, multi-room compartments could increase the complexity of these latter, reducing the accessibility of firefighters and rescue teams and compromise the compartmentation of the areas.

In our analysis, a fire risk estimation has been performed on different compartments, considering fire load characteristics, but also occupant features to achieve the acceptability of the in place-protection measures.

3.2 Fire Risk estimation of clinic visiting/consulting compartments

Such a type of compartment is frequently found in clinics and they represent more than 50% of our case studies.

These compartments could vary from few square meters to 500-600 m^2 in the case of large areas with different consulting rooms and other space for accessory services within the same compartment (i.e. cleaning service, little warehouse, nurse office, relax room, waiting room etc.). The majority of the structures we have investigated do not have a PA system installed; the alarm system is made up by manual alarm switch that enable siren sound. This type of alert induces a more late response of the occupants to fire and increase their pre-movement time. A modification in the alarm system could produce a decrease in the response time and an improvement in the risk level of the compartment.

Table 2: Number of facilities analysed, by type.

Typology	#
Hospital	2
Clinic/Day Hospital	7
Familial consultory - Psychiatric help	2
Drug-dependence patients care facility	1
Technical and administrative office	2

Table 3: Influence of alert system on risk estimate

Alarm system	Pre-movement time	Risk level
Basic (voice)	PT7	High
Manual	PT6	Medium
PA recorded messages	PT4	Low
Live directive PA	PT3	Low

3.3 High-risk compartments

A high-risk level is found in each structure with compartments like operating room, Intensive care Units (ICU), dialysis ward, Emergency Room departments (ER). These estimates found good agreement with recent Italian Fire Code, which classifies these facilities as D2 risk level. While this risk level, according to the Italian Code, imposes a defined performance level of the protection measures and building characteristics to be adopted, FLAME method has a more feasible approach: the High-risk level is mitigated only with the meanwhile presence of a sprinkler system in the compartment. Actually, this risk level is not fixed, but could be modified (in the approach of the As Low As Reasonably Possible) whether fire scenario or/and compartment characteristics are changed.
Indeed, the introduction of a PA live system could enhance the decrease of the RSET and consequently reduce the fire risk at which occupants are subjected.
The flexibility of the method could be demonstrated when assessing pre-movement time for different compartments, all classified as High-risk. Patients with low determination, medium mobility and generally scarce attitude to take attention to alarm cues characterize psychiatric ward. Dialysis ward is a peculiar compartment, where serious difficult in engaging emergency procedures are to be faced.
Pre-movement time obtained by the method for dialysis ward is equal to 20 minutes (see Figure 1); this is in good agreement with sampling survey performed in situ. The time required for disconnecting in safety a patient undergoing a dialysis treatment from the machine is about 15 minutes, to which additional minutes are to be accounted for staff response to fire principle (this depending on alert system installed).

3.4 Effect of occupancy on pre-movement time

The logic behind FLAME sheet for the assessment of the RSET through occupant parameters estimate could be appreciated in Figure 2. This approach is derived from Marchant (1999). Familiarity represent the controlling feature among the others in this estimation. The healthcare facilities compartments could be strictly controlled areas, like operating room or ICU, where a high degree of staff with reasonably good knowledge of place and emergency procedure is present, to consulting room or waiting hall, with a majority of occupants composed by patients, often occasional and rarely aware of emergency escape ways.
A peculiar case is represented by compartments like warehouses. In healthcare facilities are often present very large room dedicated to storage of both medical records and drugs, with quite high fire load and presence of fast growth-fire materials. Here the absence of a PA system increase the response to fire emergency, even if the occupants of the compartment are staff trained workers and the characteristics of the structure is favourable to a quick evacuation. The presence of a PA system could have reduced the pre-movement time and consequently the risk level to Medium.

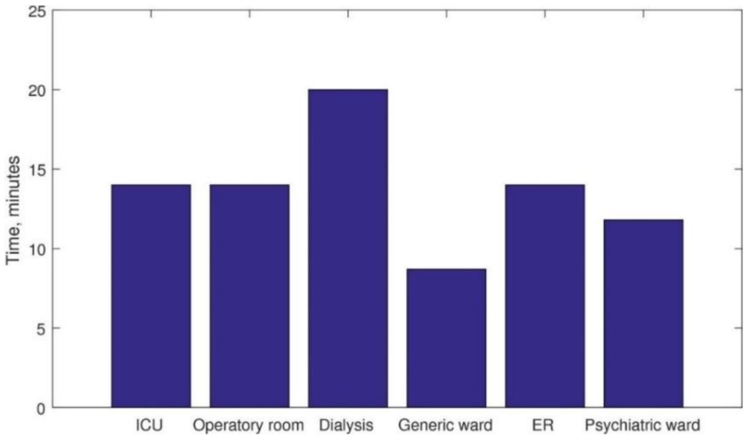

Figure 1: Pre-movement time of different compartments

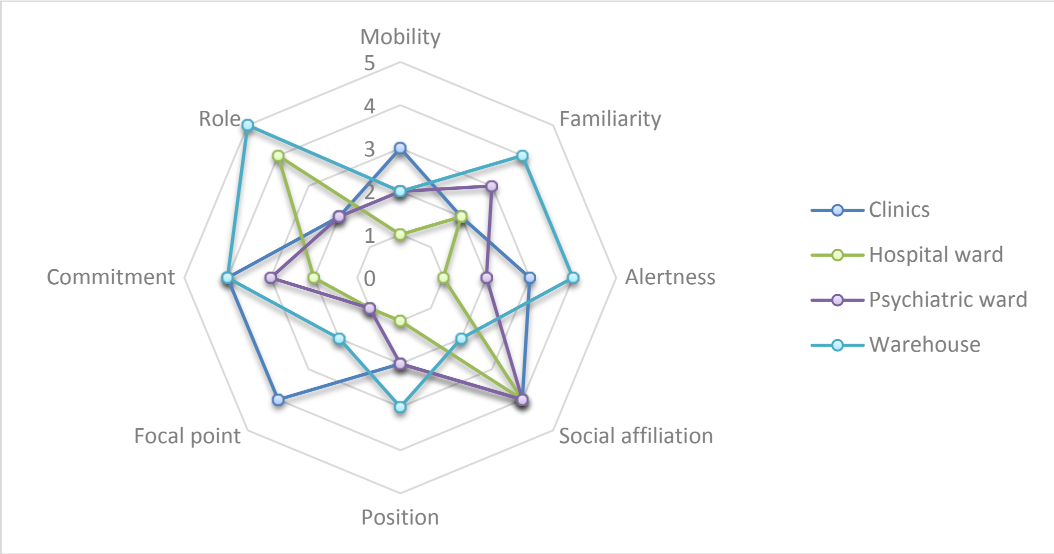

Figure 2: Radar representation of occupant characteristic to pre-movement time estimate

3.5 Protection category and acceptability by occupancy

The main purpose of FLAME application is to give a value of acceptability of protection measures adopted with respect to the fire risk estimate of compartments.

In the examples above, we have underlined the mitigation of the fire risk level according to the introduction of adequate alert system. Protection category implemented in FLAME include also the fire risk management system, thus considering all emergency procedures and good practices to be put in place by work owners.

As clinics are concerned a Medium level of risk is generally defined and a Level 3 Protection Category gives an acceptable judgement by the method approach. A "Tolerable" result is found for a Protection Category valued 2, i.e. when only manual alarm system are present (absence of automatic detectors).

Dealing with high-risk compartments, a sprinkler system is required always to find an acceptable level evaluation.

In our case ICU, operation rooms, ER department are included in this classification. The reasons are mainly due to the alert system present in these compartments, generally PA recorded messages or only automatic activated sirens. For the reasons described in previous section, the installation of PA live emergency cues could reduce the risk for the occupants (as shown in Figure 3).

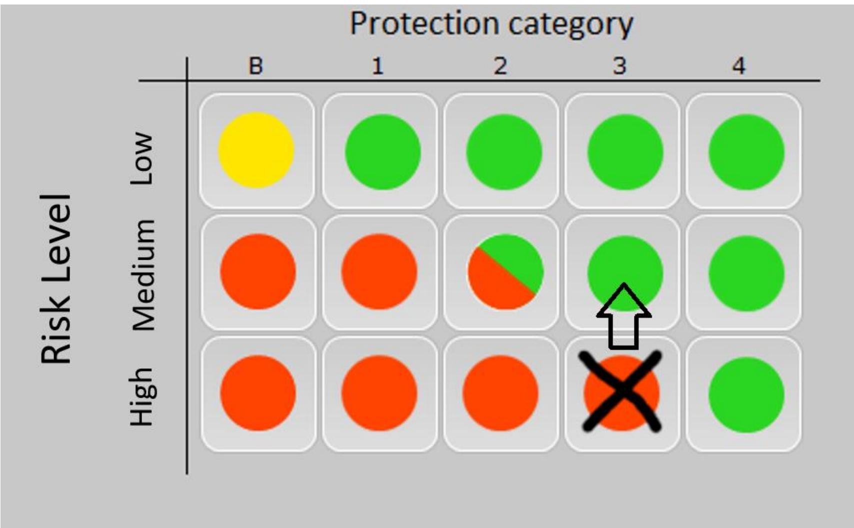

Figure 3: Acceptability in function of risk level, if PA system is introduced risk level is mitigated and acceptability is reached (red dots = "Inadequate", green = "Adequate", half-and-half = "Tolerable").

4. Conclusions

In the context of the healthcare facilities, FLAME method application could work for:

- Design phase of healthcare facilities
- Building renovation or outplacement of wards
- Risk first-phase evaluation for further analysis with more complex methods
- Underlining problematic to be faced with calculation codes or CFD simulations

The approach of FLAME is coherent with standards (Italian and worldwide) that are recently moving towards an occupant risk definition in which the key factor is defined by RSET and the evacuation capability of the people inside compartments, according to their characteristics (even psychological-dependent) rather than on fire load. The key point is that the final goal is to grant the safe escape of occupants and fire load only contribute to the gravity of the consequences on the structures up to their possible collapse. If this will occur is reasonable that the totality of the occupants is evacuated beforehand, in the early stage of the fire, when tenable conditions are still present and fire effects (smoke, heat) do not compromise people's capacity to escape.

The concept is applicable even more strictly in the case of healthcare facilities, in which an additional amount of time is often to be accounted for patients' limited readiness to fire hazard.

This contributes to raise the time required for the evacuation with respect to the available amount of time (connected to structure resilience to fire).

According to our investigation, a risk distribution sort by type of structures could be defined.

Hospitals have a 55% of High-risk compartments, while 54% of the clinics' compartments are defined as Medium. A lower than 15% fraction of compartments is classified as Low-risk for all structures, except to offices whose value is 34%. On the total number of high-risk compartments, the 60% is related to hospitals.

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