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Internal Fire Hydrants in Residential and Public Buildings as a Fire-Risk Mitigation Measure

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***Abstract*— Internal fire hydrants (IFHs) are an active measure for initial fire suppression and for supporting firefighting operations by providing immediately accessible water within the building. This paper integrates a regulatory analysis, processing of statistics for 43,127 registered fires in public and residential buildings during 2015-2025, an analysis of 66 registered fires in 2015-2024 in which an IFH was used, data from thematic inspections of 2,203 high-rise residential buildings, and a parameterized event tree for evaluating the weighted contribution of IFHs to fire-risk reduction. The analysis shows that the current regulatory framework in Bulgaria imposes measurable requirements for coverage, flow rate, pressure, minimum water-supply duration, and maintenance. Of the 66 incidents analyzed, 63 (95.5%) involved an IFH reported as operational, yet inspections of the building stock reveal a widespread presence of latent deficiencies - missing equipment, lack of maintenance, and missing signage. This confirms that the actual risk-reduction effect of IFHs depends simultaneously on their regulatory provision, technical readiness, and the human factor. Primary numerical results from the questionnaire surveys and experiments are not available in the uploaded files; therefore, the paper shows how these data enter the model without introducing unsupported values.**

Keywords*— *internal fire hydrants; building firefighting water-supply installations; fire risk; event tree; reliability; maintenance; residential and public buildings.

I. Introduction

Internal fire hydrants (IFHs) are a component of building firefighting water-supply installations intended to provide immediate access to water for first intervention and/or to support the actions of fire-service crews. In the international engineering framework, these systems are treated as active barriers whose contribution depends on adequate water delivery, reliability, and readiness for use [1]-[9]. EN 671-1 and EN 671-2 explicitly define hose systems as intended for use by occupants, whereas EN 671-3 places emphasis on maintenance so that the systems can guarantee an initial emergency intervention for fire extinguishment [3]-[5].

In the Bulgarian regulatory system, the technical requirements for building firefighting water-supply installations (BFWSIs) with IFHs are governed primarily by Ordinance No. Iz-1971, whereas operational requirements are governed by Ordinance No. 8121z-647. From the perspective of fire-risk assessment, the decisive question is not merely whether an IFH is installed, but whether it is required by the code, whether it is operational, and whether it is actually used at a sufficiently early stage of fire development [1], [2]. Early water application is critical for limiting consequences, a finding also confirmed by large-scale experimental studies of firefighting operations published by NIST and FSRI [10], [11].

This paper combines a regulatory analysis, processing of the provided statistical files, results from thematic inspections, and a developed event tree through which IFHs are formalized as a fire-risk mitigation measure. The approach is parametric: instead of introducing fictitious estimates, the model shows how the different data groups are linked to branch probabilities and expected consequences.

II. Aim, Data and Methods

The aim of the paper is to assess internal fire hydrants in residential and public buildings as a fire-risk mitigation measure through an integrated analysis of: (i) the current regulatory requirements; (ii) the registered fires in which an IFH was used; (iii) data from thematic inspections of the building stock; and (iv) a mathematical model of the alternative outcomes after fire occurrence.

The empirical part uses data from the General Directorate Fire Safety and Civil Protection of the Ministry of Interior, systematized by the author into three groups: summary statistics for fires in public and residential buildings for the period 2015-2025; fires in which an IFH was used; and results from thematic inspections of high-

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rise residential and public buildings. Data from questionnaire surveys conducted among the population were also used.

The statistical analysis includes descriptive indicators, relative shares, and Wilson confidence intervals for key proportions. The logical structure is organized as an event tree (Event Tree Analysis, ETA), which makes it possible to trace all relevant outcomes after the initiating event and to determine the contribution of each barrier to the reduction of expected consequences [9].

An important limitation is the lack of data on how many of all registered fires occurred in buildings equipped with IFHs. For that reason, the ratio Nused / Nfires does not represent the conditional effectiveness of IFHs, but only a joint estimate of presence, operability, and actual use during fire. The primary numerical results from the questionnaire and experimental studies mentioned in the working materials are also unavailable; therefore, they are treated here as model parameters without introducing unsupported values.

III. Regulatory Requirements in the Republic of Bulgaria

The current Ordinance No. Iz-1971 does not require BFWSIs with IFHs for buildings in subclasses F1.3 and F1.4 with a maximum height of human occupancy up to and including 25 m, nor for buildings or parts of buildings in groups F1-F4 (except F1.3 and F1.4) with a volume up to 5,000 m3. For buildings outside these exemptions the requirement is triggered, and for buildings with a maximum height of human occupancy above 25 m in groups II-IV the installation must be looped (closed) [1]. This means that the presence of IFHs is normatively determined by the building's functional purpose, volume, and height.

The Ordinance also imposes measurable engineering criteria: fire hydrants are to be located at accessible places near entrances, corridors, and foyers; all rooms must fall within the reach of the compact jet; the minimum radius of the compact jet is at least 6 m; the required flow rates and the number of simultaneously operating hydrants are determined by tabulated requirements; and the water quantity must be ensured for at least 1 h. Where automatic water-based fire-extinguishing installations are present, simultaneity of water demand is also taken into account [1], [3], [4].

At the operational level, Ordinance No. 8121z-647 requires fire hydrants to be maintained in accordance with the manufacturer's operating instructions and BDS EN 671-3, with maintenance carried out by persons and traders authorized under the Ministry of Interior Act [2], [5]. Within the framework of state fire control, the procedure and conditions for inspections of facilities are regulated by Ordinance No. 8121z-882 [12].

The historical review in the working materials provided shows a substantial evolution of the threshold for residential buildings: no requirement in 1951-1956; a requirement for all buildings above 5 storeys in 1956-1959; above 6 floors in 1959-1963; withdrawal of the requirement in 1963-1972; reinstatement for buildings above 10 floors in 1972-1978; a criterion of above 10 storeys or 30 m in 1978-2009; above 28 m in 2009-2025; and the current threshold of above 25 m from 2025 onward. In this sense, high-rise residential buildings constitute the most clearly identified class of facilities for which IFHs have both regulatory and operational significance.

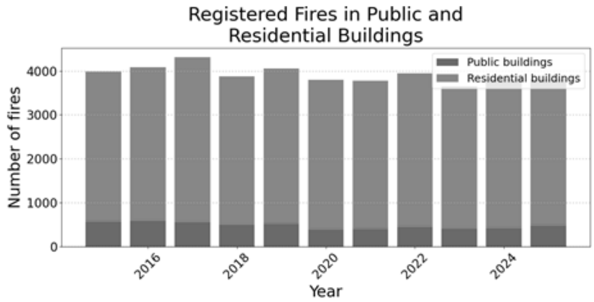

Fig. 1. Registered fires in public and residential buildings by year (2015-2025); author's processing of the uploaded fire-statistics dataset.

A. Total Number of Fires in the Building Categories Considered

During 2015-2025, a total of 43,127 fires were registered in the public and residential building categories considered, of which 5,237 were in public buildings and 37,890 in residential buildings. Residential buildings account for approximately 87.9% of all registered fires within this scope, which explains why the absolute number of cases in which an IFH was used is also higher for this category.

B. Fires in Which an IFH Was Used

A total of 66 fires were identified in 2015-2024 in which use of an IFH was recorded: 44 in residential buildings and 22 in public buildings. By year, there is no monotonic trend; a local maximum is observed in 2017 (11 cases), and a minimum in 2021 (3 cases).

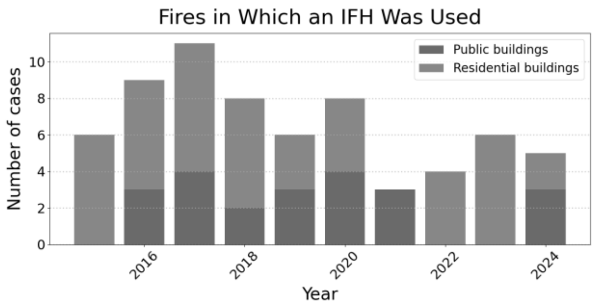

Fig. 2. Fires in which an IFH was used, by year and building type (2015-2024); author's processing of the uploaded datasets on IFH use in public and residential buildings.

In these 66 cases, IFHs were used by firefighters in 60 cases (90.9%) and by on-site persons - occupants or staff - in 6 cases (9.1%). For public buildings the ratio is 21 to 1, and for residential buildings 39 to 5. The reported operability of the IFH used was 63/66 = 95.5%; the 95% Wilson confidence interval is 87.5-98.4%. It is important to emphasize, however, that this share describes only the cases in which there was actual demand for or use of an IFH, not the condition of the entire building stock.

Among residential buildings, 27 of the 44 cases (61.4%) were marked as high-rise buildings. Floor information is available for 36 cases, and 18 of them (50.0%) occurred on the 11th floor or higher. This supports the engineering relevance of IFHs in conditions of vertical building development, where pressure deficit with height and the time needed to reach the seat of fire become more critical.

When related to all registered fires in public and residential buildings over the same period, the cases in which an IFH was used amount to 0.168% overall, 0.462% for public buildings, and 0.127% for residential buildings. These values are not an estimate of IFH effectiveness, because the denominator does not contain information on whether an IFH was actually present in the building. Formally, the observed share is closer to P(IFH used ∩ IFH operable ∩ IFH present | fire) than to P(IFH used | IFH present and operable, fire).

In public buildings, the largest number of cases involving IFH use was recorded in accommodation and food service activities (10), followed by public administration (4) and education (3), which may be explained both by the characteristics of the building stock and by the presence of staff on site.

C. Inspections and Latent Failures

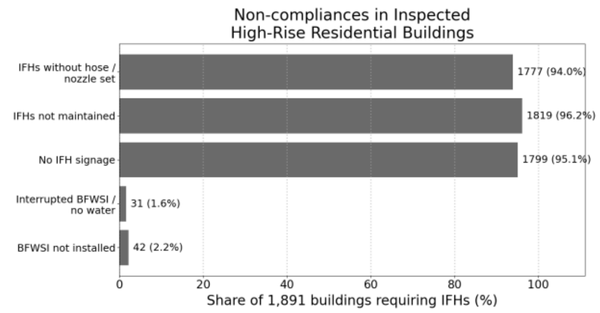

Fig. 3. Non-compliances identified in inspected high-rise residential buildings; shares are calculated relative to the 1,891 buildings in which IFHs were required; author's processing of the uploaded thematic-inspection dataset.

Among the 1,891 buildings in which IFHs were required, 1,777 IFHs lacking hoses or nozzles were recorded (94.0%), 1,819 IFHs not maintained (96.2%), 31 cases of interrupted BFWSI or lack of water (1.6%), 42 cases of a BFWSI not installed in violation of construction rules (2.2%), and 1,799 cases with no IFH signage (95.1%).

Inspection of 187 high-rise public buildings established that IFHs were required in all facilities and that there were no cases of a missing BFWSI. Violations were found in 17 facilities: 5 IFHs lacking equipment, 15 not maintained, 1 interrupted BFWSI/no water, and 15 without signage.

At first glance, the high reported operability in real incidents and the massive deficiencies identified by inspections appear contradictory. In fact, however, they describe different conditional sets. The list of 66 fires contains cases in which an IFH had already been sought or used, whereas the inspections describe the condition of the available building stock before a fire occurred. Consequently, the inspections reveal latent failures that may break the barrier before it is ever activated.

IV. Event Tree and Mathematical Model

ETA is an inductive procedure that considers all possible outcomes after an initiating event, taking into account whether the protective barriers function or fail [9]. For the purposes of this paper, the initiating event is F_0 - occurrence of a fire in a residential or public building - and the relevant barriers are: normative presence of a BFWSI with IFHs, technical operability, actual tactical choice of use, and the human factor among occupants.

The full event tree was developed in a separate working file, and Fig. 4 presents the event-tree logic used in the mathematical model.

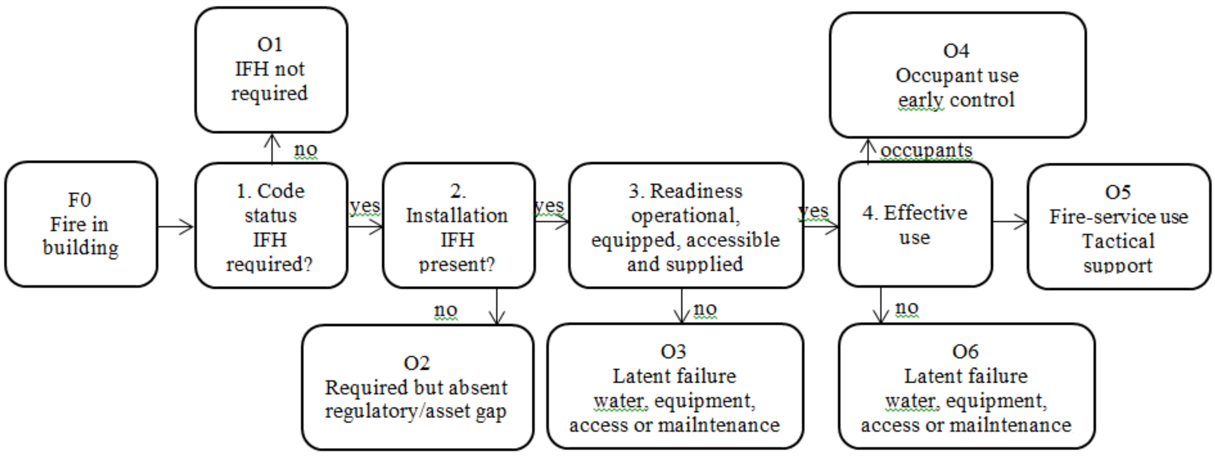

Fig. 4. Simplified event tree for internal fire hydrants used in the generalized model

TABLE I. MAIN PARAMETERS USED IN THE GENERALIZED EVENT-TREE MODEL

Parameter	Meaning and primary data source
pREQ	IFH required by code for the building/fire case; regulatory classification and building-stock data.
pINS	Required IFH physically installed; inspections, commissioning and asset records.
pRDY	Installed IFH operational, equipped, accessible and supplied; functional inspections and maintenance records.
pO, pG, pN	Use by occupants, by fire service, or no effective use; fire-incident reports, drills and surveys.
pC, pT	Correct/timely occupant action and tactical fire-service use; training records, experiments and incident narratives.
Lk, etak	Loss and loss-reduction factor for terminal state Ok; incident outcomes, expert calibration and simulations.

The generalized model is written at the level of the initiating fire event F0. It separates three different questions that should not be merged statistically: whether an IFH is required and installed, whether it is ready at the moment of demand, and whether it is used early enough to reduce consequences. Table I summarizes the main parameters. This separation prevents the 66 recorded use cases from being interpreted as a direct measure of effectiveness for the whole building stock.

The terminal states of the simplified tree are: O1 - IFH not required; O2 - required but absent; O3 - installed but not ready; O4 - early occupant use; O5 - fire-service use; and O6 - no effective or timely use. With pO+pG+pN=1, the branch probabilities can be written as:

$$P_{\left(\frac{O1}{F_0}\right)=1-pREQ} \quad (1)$$

$$P_{\left(\frac{O2}{F_0}\right)=pREQ.(1-pINS)} \quad (2)$$

$$P_{\left(\frac{O3}{F_0}\right)=pREQ.pINS.(1-pRDY)} \quad (3)$$

$$P_{\left(\frac{O4}{F_0}\right)=pREQ.pINS.pRDY.pO.pC} \quad (4)$$

$$P_{\left(\frac{O5}{F_0}\right)=pREQ.pINS.pRDY.pG.pT} \quad (5)$$

$$P_{\left(\frac{O6}{F_0}\right)=pREQ.pINS.pRDY.(1-\,pO.pC-pG.pT)} \quad (6)$$

The failure causes observed during inspections are attached to the readiness branch. If qj is the conditional probability of failure cause j when an installed IFH is not ready, then:

$$\sum q_j = 1 \quad (7)$$

j ∈ {water/pressure, equipment, access/signage, maintenance}

Thus, missing hoses/nozzles, lack of maintenance, inaccessible cabinets, missing signage, and pressure or water-supply problems do not make the event tree more complicated; they explain how the readiness probability pRDY should be estimated and improved.

If Lk is the expected loss for terminal state Ok and R0 is the reference risk without IFH contribution, the expected risk with IFHs is:

$$RIFH = P_{(FO)} \cdot \sum_{k=1}^{6} P_{\frac{O_k}{F_0}} . L_k \quad (8)$$

The weighted contribution of IFHs as a risk-mitigation measure is expressed as the relative reduction of risk:

$$WTFH = \frac{R0-RIFH}{R0} \quad (9)$$

Equivalently, when Lk = L0.(1-etak), where etak is the fractional loss reduction in terminal state Ok, the contribution can be interpreted as a probability-weighted sum of the reductions achieved by the terminal branches:

$$WIFH = \sum_{k=1}^{6} P_{\frac{O_k}{F_0}} . \eta_k \quad (10)$$

The human-factor terms are estimated separately from technical readiness. For example, pC may be estimated as the share of respondents or trained occupants who describe the correct and safe sequence of actions, while time-to-water application can be compared with a critical threshold tcrit. The important modeling rule is that survey and drill results populate pC and pO; they do not substitute for measured pRDY.

This form is deliberately compact. It can be populated with available national statistics, building inspections, maintenance records, fire-incident data, occupant surveys and drill results, while preserving the distinction between code compliance, technical availability and actual use. Reliability and maintainability concepts remain important because hidden failures are revealed only when the system is inspected or demanded [12], [13].

V. DISCISSION

The revised event tree highlights that IFHs reduce fire risk only when four barriers work in sequence: the system is required for the building, it is physically present, it is technically ready, and it is used at a stage when water application can still influence fire development. This interpretation is more useful for practice than a single effectiveness percentage, because each branch corresponds to a concrete management action.

The high reported operability in the 66 fires with IFH use should therefore be interpreted with caution. These cases are conditioned on the fact that the IFH was already found, selected and used. They cannot be generalized to all fires in buildings where an IFH may have been absent, inaccessible, incomplete, unmaintained or not considered by occupants. The inspection results are essential because they describe latent failures before demand, which is the critical point for a hidden protection system.

For inspections, the practical implication is to move beyond a visual check of the cabinet. A risk-based inspection protocol should include: verification that an IFH is required for the building; confirmation that the installation is present and accessible; control of hose, nozzle and handwheel completeness; inspection of cabinet signage and opening; review of maintenance documentation; and functional pressure/flow testing at the hydraulically most unfavorable point. High-rise residential buildings should be prioritized because vertical development increases the importance of pressure, access time and tactical support.

For maintenance, the model shows that the most efficient interventions are those that increase pRDY. Missing hoses and nozzles, unmarked cabinets and overdue maintenance are not minor administrative issues; they move the fire into a branch with no effective IFH contribution. Building managers should keep a simple register containing the location of each cabinet, date of last inspection, identified defects, corrective action, contractor, and next due date. Tamper-evident seals, standardized spare equipment and clear responsibilities for monthly visual checks can reduce repeated deficiencies.

For occupants and staff, the results point to a different intervention: increasing pO and pC without compromising evacuation safety. Training should be short, practical and limited to safe first actions: recognizing the cabinet, calling the fire service, avoiding smoke exposure, using the hose only for incipient fires when an escape route remains available, and stopping use when conditions become unsafe. In public buildings with staff on site, annual familiarization and short drills are justified. In residential buildings, information boards, instructions inside the cabinet and building-manager briefings are more realistic than complex drills for all occupants.

For fire-service operations, IFHs appear to be especially relevant as a tactical support measure. In the analyzed residential cases, the system was used mainly by fire-service crews rather than by occupants. This means that design and maintenance should support professional use: unobstructed access to cabinets, predictable location, reliable pressure at height, looped installations where required, and information about the installation available to responding crews.

For reporting, the current data structure is the main barrier to a stronger quantitative assessment. Future fire-incident forms should include fields for: whether an IFH was required; whether it was present; whether it was operational and complete; who used it; whether water, pressure or access problems occurred; approximate time to water application; and whether IFH use affected localization, spread, casualties or material loss. These fields would allow direct estimation of P(successful use | IFH present and ready, fire), rather than relying on indirect ratios.

Finally, the model can support prioritization. Branch O2 identifies regulatory or asset gaps; O3 identifies maintenance and readiness problems; O4 and O5 identify successful use; and O6 identifies cases where a present system did not influence the outcome. Reporting the share of inspections or incidents in each branch would give authorities and building owners a simple set of performance indicators. This is consistent with broader fire-safety assessment practice, where the value of a protective measure depends on both technical reliability and organizational readiness [14].

VI. Conclusion

1) The regulatory framework in the Republic of Bulgaria sets engineering-measurable requirements for BFWSIs with IFHs - concerning presence in specific building classes, location, coverage, flow rate, pressure, simultaneity and minimum water-supply duration [1]-[3], [8], [9].

2) The statistical files provided include 43,127 registered fires (2015-2025) and 66 cases (2015-2024) in which IFH use was recorded. The 63 operational IFHs among these 66 cases (95.5%) describe only recorded use cases and should not be interpreted as the readiness of the entire building stock.

3) The thematic inspections show substantial latent deficiencies - missing equipment, lack of maintenance and missing signage. These findings directly affect the readiness probability pRDY and are therefore central to the actual risk-reduction effect of IFHs.

4) The simplified event tree and generalized mathematical model express IFHs as a sequence of barriers: requirement, presence, readiness and timely use. The model is easier to reproduce because failure causes are handled as diagnostics of the readiness branch rather than as numerous terminal states.

5) The most immediate practical measures are stricter functional inspections, restoration of missing equipment, visible and standardized signage, clear maintenance registers, short occupant or staff instructions, and better integration of IFHs into fire-service tactical planning.

6) A more complete quantitative assessment requires improved incident reporting. Future records should capture IFH requirement, presence, condition, user type, time to water application, technical problems and observed effect on fire development and losses.

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