

# SFPE EUROPE



AN OFFICIAL PUBLICATION OF SFPE

## Quantifying Costs and Benefits from Fire Protection in Buildings

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The economic impact of fire needs to be considered on a macro and micro scale, from the national impact to the cost of fire protection and return on investment. This article presents the outcomes of the project “Economic Impact of Fire: Cost and Impact of Fire Protection in Buildings” which was carried out from October 2021 to July 2022 with the support of the NFPA Research Foundation. The project established and applied a methodology for evaluating the total benefits and costs related to fire protection features in buildings, such as sprinklers or passive fire protection. The methodology, based on Present Net Value (PNV) evaluation, provides a systematic approach to assess cost effectiveness of investments in fire safety features while accounting for the various dimensions of fire impact and fire losses. The methodology has been applied to five case studies with different building types. Sensitivity studies allow evaluating the robustness of the cost-benefit evaluations and highlighting the effect of input data on the outcome. The proposed methodology can support decision making for policy makers, insurance companies, and individual building owners, to inform the most efficient investments for fire safety.

### Introduction

Cost-effectiveness is a key consideration within fire safety engineering. Cost-Benefit Analysis (CBA) can be used to determine the cost-effectiveness of investments in fire protection. This is of interest to (i) code-makers and legislators when prescribing fire safety measures for a class of buildings, and (ii) private decision-makers when considering whether to invest in additional safety for a specific project. The focus on cost-effectiveness acknowledges that additional safety investments are always possible. With increasing safety level, however, the marginal benefit diminishes. To guide decision-making, CBA methodologies are needed that provide a systematic approach to weigh the costs and benefits of fire protection investments.

This project, supported by the NFPA Research Foundation, developed a methodology for evaluating the total benefits and costs related to fire protection features in buildings. The methodology is based on calculation of the cost of installation, on-going maintenance, and the expected beneficial impact of building fire protection on direct and indirect losses in case of fire. The calculation draws on a combination of probabilistic/reliability theory, data analysis, and advanced numerical modeling to predict the fire induced damage and property loss in buildings protected with different features. The methodology has been applied to calculate the total benefits and costs for five case studies of fire protection features in buildings.

## **State-of-the-art Review on Cost of Fire Protection, Fire Losses, and Cost-Benefit Analysis**

The assessment of the cost effectiveness of fire protection features in buildings requires the capability to quantify (i) the investment cost of these features and (ii) the averted fire losses from the presence of these features. Besides, (iii) a method is required to compare these cost components. Therefore, the project started with a literature review focused on these three key components:

1. *Evaluation of Cost of Fire Protection*: review of the methods and data for calculating the cost of a fire protection system for a building. Fire protection costs can be evaluated at two levels. At the micro level, the cost of the systems is evaluated in single buildings or group of buildings belonging to a private entity, through summation of the total cost of materials, labor and equipment required for the installation and maintenance of said systems. At the macro level, the expenditure on fire protection in buildings is estimated at the societal level [1], either as a fraction of the total expenditure on construction using cost multipliers, or via a compilation of data on sales of fire protection equipment and materials. Challenges associated with the collection of sales data makes the use of cost multipliers and data on construction expenditure the more viable method for computing these costs. However, this method comes with its own challenges, particularly with grouping buildings into classes in order to compute a class wide multiplier that will adequately reflect the fire protection cost for each building in the class.

2. *Evaluation of Fire Losses*: review of the methods and data for calculating the fire losses in a building. The fire losses are primarily divided in direct and indirect losses. Direct losses refer to the *“damage caused to a building, its contents and occupants during the course of a fire”* [2], hence they have a material (structural and non-structural elements, plus content) and human component (fatalities and injuries of civilians and fire fighters). Indirect losses are defined as the *“costs associated with a fire after it is extinguished”* [2]. Examples include the cost associated with unavailability or loss of an infrastructure with a critical function or of unique value, the damage to the environment and pollution/waste, the losses incurred due to business interruption, as well as cascading effects with suppliers or clients of an affected company. As different scenarios result in different losses, the losses are weighted according to their likelihood of occurrence.

3. *Methods for Cost-Benefit Analysis of Fire Protection in Buildings*: review of the methods used to weigh the costs and benefits of fire protection investments and draw decisions from this assessment. The review highlights minimum components of a cost-benefit evaluation: (i) cost and benefits should be considered at constant prices (i.e., corrected for inflation where necessary); (ii) costs and benefits should be discounted to allow for the comparison of up-front, future, and recurring costs; (iii) all risk-reduction effects should be taken into account to fully value the benefit of fire protection measures. This includes the need to take into account reduction in the risk to life. The review further highlighted two main approaches for cost-benefit evaluations: (a) a total net benefit (present net value or PNV) evaluation and (b) a cost-benefit ratio or benefit-cost ratio (CBR or BCR) evaluation. Both approaches are equivalent when considering a binary question (single design alternative), such as whether or not to invest in sprinkler

protection for a given reference design. As soon as multiple design alternatives are compared, however, comparing BCR or CBR values is not meaningful and a PNV evaluation is needed.

### Methodology for Cost-Benefit Analysis of Fire Protection in Buildings

The proposed methodology relies on the following building blocks: (i) the concept of discounting cash flows; (ii) the relevant cost components; (iii) the combination of these cost components into the PNV evaluation. Figure 1 shows a flowchart illustrating how the evaluation of costs and losses feeds into the cost-benefit analysis to support decision-making and optimization of fire protection features in buildings. Note that the costs and benefits are evaluated from the perspective of the (idealized) decision-maker. The distinction between societal and private decision-makers is crucial as the societal requirements for safety define a lower bound safety level for further private considerations [3], and besides, the valuation of costs at a societal level and at a private level are generally different. For further details on the methodology and equations, the reader is referred to the technical report [4].

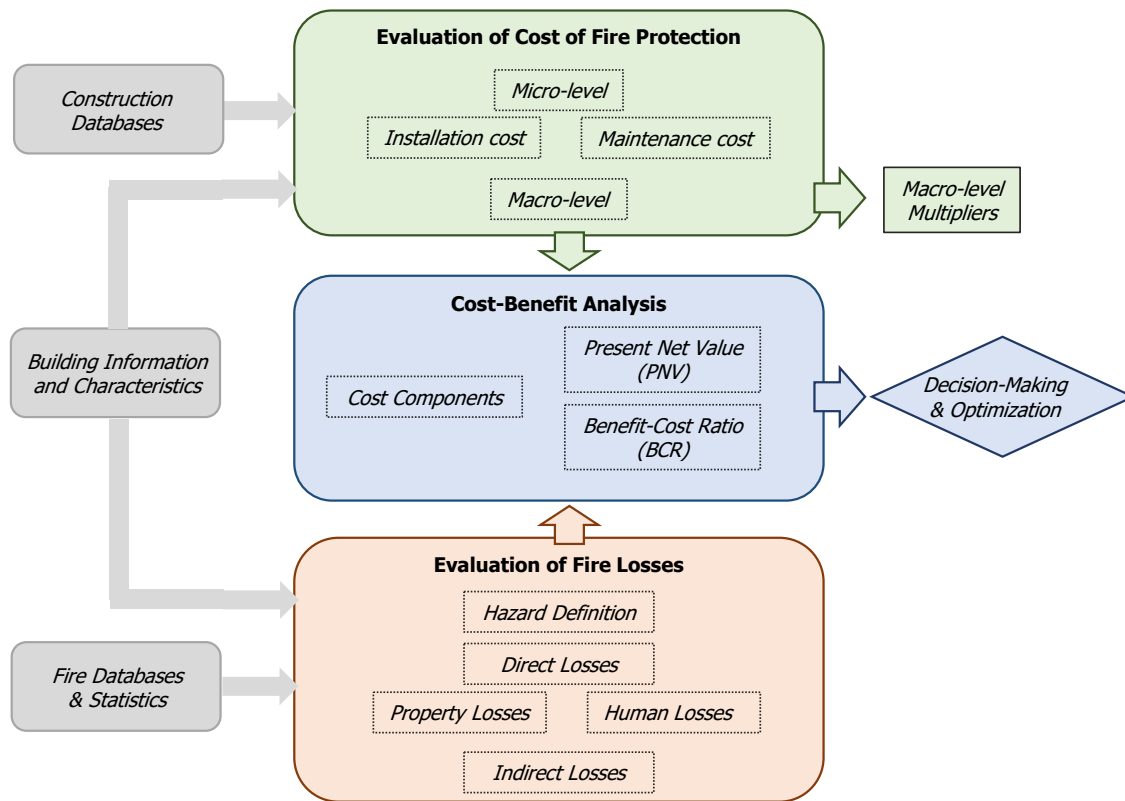


Figure 1. Components within the assessment of the economic impact of fire.

### Case Studies

The methodology is applied to five case studies. Details on the case studies and results can be found in the technical report [4]. The case studies include the assessment of the net benefit for:

- (i) Sprinklers in a residential single-family dwelling
- (ii) Sprinkler and compartmentation in a warehouse
- (iii) Detection system and additional staircase in a multi-story government building
- (iv) Passive fire protection on steel framing members in a multi-story office building

(v) Sprinklers and encapsulation in a multi-story residential mass timber building

The case studies are executed from the perspective of a code-maker and thus adopt a societal perspective on costs and benefits. The calculations are completed in Jupyterlab (Python) scripts which will be provided through the NFPA Foundation website. The case studies start from the existing level of fire protection in society. This allows for the consideration of fire statistics in evaluation of fire losses.

For case studies (iv) and (v), evaluation of losses (and averted losses owing to the fire protection measures) relies on numerical simulations of the fire performance of the structure. These simulations complement statistical data as fire loss data are typically not sufficiently detailed to differentiate between similar buildings with varying amount of passive fire protection. Probabilistic thermomechanical simulations with the finite element software SAFIR are used to assess the probability of reaching different damage states [5] and, from there, infer the direct and indirect losses in case of a structurally significant fire.

The first case study is briefly summarized hereafter. The building prototype is a two-story wood light-frame house with a total floor area of 210 m<sup>2</sup>. Fire detection is considered to be present as minimum required safety feature. The net benefit of sprinkler protection is assessed. The costs are evaluated through the RSMeans database. A discount rate of 3% is adopted. The installation cost multiplier for sprinklers is 0.9% of the construction cost. An annual maintenance cost of 5% is taken into account for the sprinklers. To evaluate the benefits from the sprinklers, the following parameter values are adopted (see full report for background and references): fire frequency 0.00151 per year [6]; sprinkler efficiency 0.95; civilian fatality rate 7.4 per 1,000 reported fires; firefighter fireground fatality rate 2.4 per 100,000 reported fires; content loss 50% of the construction cost for the damage area; indirect loss 100% of direct losses. The risk to life is assessed through the Value of a Statistical Life (VSL) concept, set at 5.7 million USD per fatality. Note that this value refers to the valuation of risk reduction, and should not be misunderstood as setting a monetary value on identifiable human lives. Sprinklers, when effective, reduce the average damage area (from 35.7 m<sup>2</sup> to 4.9 m<sup>2</sup>), reduce the civilian injuries by 57%, and reduce the civilian and firefighter fireground fatalities to zero [7].

The calculation in the case study of sprinklers in the single family house shows that the presence of sprinklers reduces the (statistical, lifetime) fire-induced losses by \$8,400, while the total cost of having the sprinklers (investment and maintenance over the life of the building) is \$6,500. The PNV is thus positive (\$8,400-\$6,500 = \$1,900) and the investment in sprinklers is recommended in this example. Figure 2 shows the breakdown of the cost components in the PNV evaluation. Since the PNV of the reduction in losses obtained from the sprinklers exceeds the PNV cost of the sprinklers, the sprinklers are cost-effective.

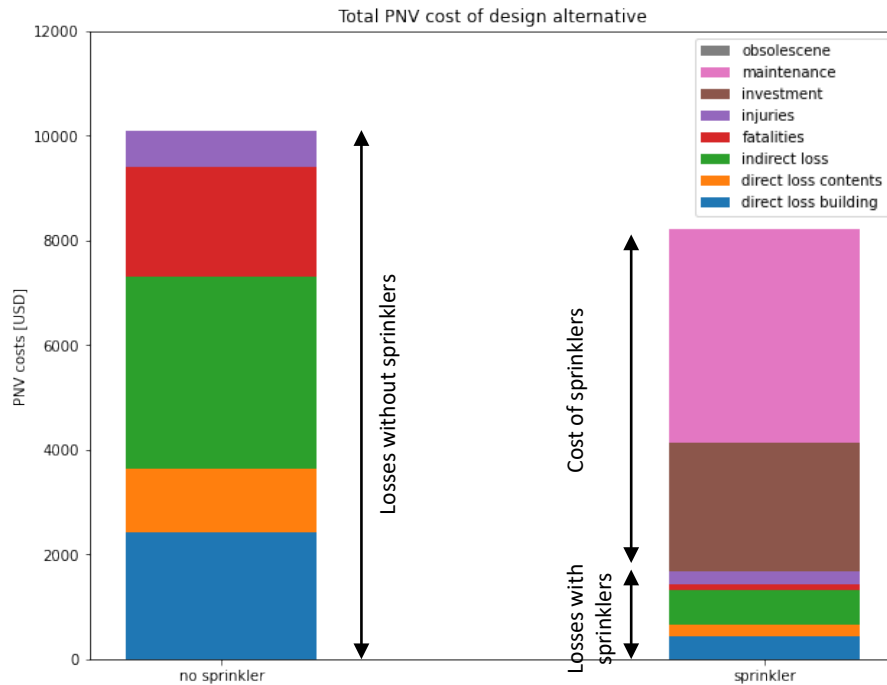


Figure 2. PNV breakdown for a case study of sprinkler installation in a single-family home. In this example, sprinklers are cost-effective because sprinkler total (lifetime) costs are \$6,500 but averted losses are \$8,400.

Figure 3 shows a sensitivity analysis. The assumptions on VSL and on indirect loss markedly influence the PNV. Sprinklers are recommended when the PNV is positive. As can be seen, the higher the VSL, the more cost-efficient the sprinklers (because of their effect on life safety). On the opposite, when VSL and indirect losses are less valued, investments in fire safety features such as sprinkler cease to be efficient. The proposed methodology allows systematically quantifying these different cost components to support investment decisions based on the specific inputs as illustrated herein. While the conclusion on cost-effectiveness depends on the chosen values for the inputs, this should not be misunderstood as indicating that “you can get any outcome you want by appropriately choosing input values”. On the contrary, the PNV methodology makes clear in which conditions the fire safety investment is cost-effective, and thus helps stakeholders in objectifying discussions.

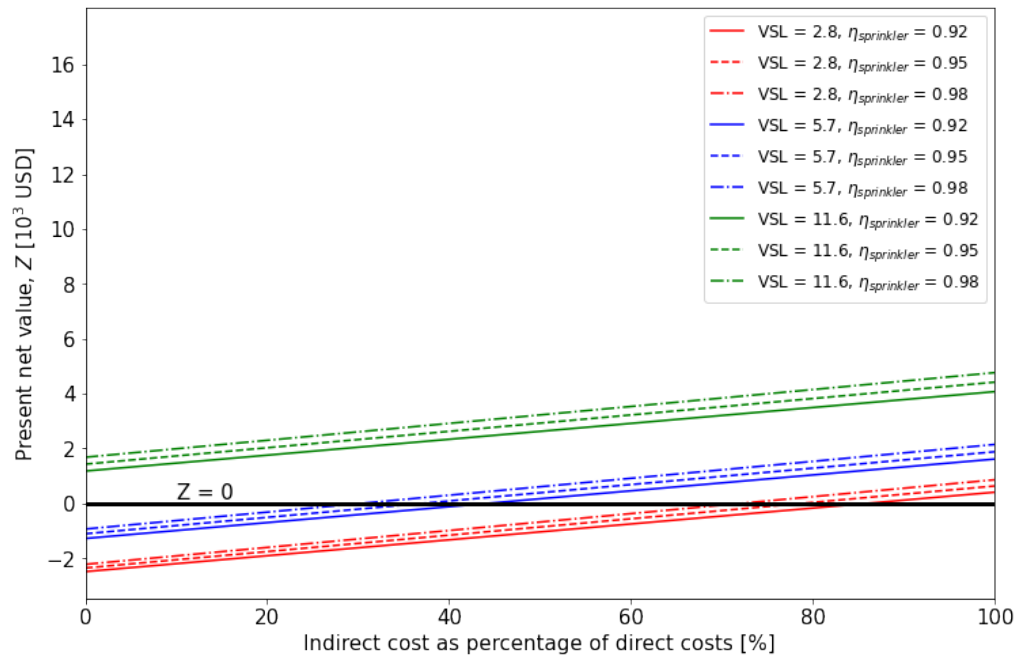


Figure 3. Sensitivity analysis for a case study of sprinkler installation in a single-family home. Cost-effectiveness of the sprinklers depends on the Value of Statistical Life and indirect cost. Small changes in sprinkler reliability do not have a major impact on the cost-effectiveness. Sprinklers are recommended when the PNV is positive.

## Conclusion

A prototype methodology was developed for the cost-benefit analysis of fire protection measures, following an in-depth review of the state-of-the-art. A present-net-value (PNV) evaluation is recommended for all situations where multiple design alternatives are to be compared. The cost components were mapped, both with respect to the investment cost and the fire-induced losses, and prototype methodologies for the assessment of cost components were developed. Case studies demonstrate the application of the methodology. It is hoped that the application of cost-benefit analyses can help stakeholders in objectifying discussions on fire safety investments, and input parameters.

The authors gratefully acknowledge the Fire Protection Research Foundation (FPRF) and the National Fire Protection Association (NFPA) for the funding. The authors thank Amanda Kimball, Birgitte Messerschmidt, and the members of the Project Technical Panel for their support.

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