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MASTER EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MASTER

Analysis of additional fire protection measures in energy poor dwellings in Spain

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Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

Analysis of additional fire protection measures in energy poor dwellings in Spain

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Agradecimientos

Gracias a mi familia por darme la oportunidad de realizar este master y estar siempre cuando los necesito.

A Blanca por soportarme estos dos años cuando las cosas no iban como quería.

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Analysis of additional fire protection measures in energy poor dwellings in Spain

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Entidad Colaboradora: ICAI – Universidad Pontificia Comillas

RESUMEN DEL PROYECTO

En este trabajo se pretende evaluar si la pobreza energética tiene relación con el riesgo de incendio. Para ello se han realizado unas encuestas a familias que sufren de pobreza energética y se ha colaborado con la ONG A+Familias para conocer las condiciones en las que se encuentran los hogares de dichas familias. Con la información recogida se han modelado 5 escenarios, siendo el primero un habitación común y el resto presenta cada uno los elementos con mayor riesgo de incendio como puede ser la presencia de radiadores eléctricos. Se han utilizado software como FDS y Smokeview para la simulación de los incendios, y con los resultados se ha evaluado la propagación del incendio y los humos en cada escenario. Con esto se ha concluido que efectivamente la pobreza energética tiene una influencia elevada en el riesgo de incendio y se han dado posibles soluciones para este problema que va en aumento.

Palabras clave: Pobreza energética, incendio, FDS, HRR

1. Introducción

Todos los años hay un gran número de muertes a causa de los incendios, sobre todo en invierno. Estos incendios son en su mayoría sufridos por aquellas familias que viven en condiciones de pobreza energética, que debido a la falta de recursos cuentan con dos opciones, o renunciar a su confort térmico o hacer uso de ciertos electrodomésticos con un mayor riesgo de incendio asociado, pero más asequibles, como por ejemplo las estufas eléctricas.

Cabe destacar algún ejemplo, como el que tuvo lugar en Huelva en enero de 2020 en el que fallecieron un bebé, su madre de 24 años y su tío de 15. El incendio estuvo causado por una estufa eléctrica, que como se ha comentado previamente es uno de los métodos más comunes y baratos para combatir las bajas temperaturas en invierno. [1]

2. Definición del Proyecto

Para la elaboración de este proyecto se ha colaborado con la ONG A+Familias, que ha facilitado información acerca de las condiciones en las que habitan las familias que sufren de pobreza energética y que colaboran con dicha ONG. Con la información obtenida se han definido los escenarios que se estudiarán a lo largo del trabajo y recogen algunos de los principales peligros a los que se ven sometidos diariamente estas familias. [2]

El objetivo de este trabajo es demostrar que la pobreza energética tiene un papel muy importante en el riesgo de incendio y exponer las principales carencias y las necesidades para poder mejorar las condiciones de estos hogares.

3. Descripción del modelo/sistema/herramienta

Para la simulación de los escenarios de incendio se hará uso de los software FDS y Smokeview. Con dichos programas se modelarán las habitaciones y se simularán los 10 primeros minutos del incendio, debido a que son los más críticos. En las simulaciones se utilizará un mobiliario para el cual habrá que definir las propiedades de los materiales así como sus curvas de tasa de liberación de calor (HRR). Para cada mueble se analizará si se produce un fuego constante, es decir si no se consume en los 10 minutos de incendio, o si por lo contrario si se irá consumiendo y reduciendo así su HRR con el paso del tiempo. A su vez se tendrá en cuenta el comportamiento de las ventanas, que cuando son sometidas a una cierta diferencia de temperatura entre el exterior y el interior se romperán debido al choque térmico. [3]

Además, se colocarán una serie de sensores en el centro y en la puerta de la habitación, así como dos planos que dividirán la habitación en cuadrículas para medir la temperatura y evaluar las condiciones interiores.

4. Resultados

Para cada escenario se evaluarán las temperaturas así como la evolución del fuego y del humo en una serie de momentos específicos, como al inicio del incendio, el instante en el que se rompe la ventana por el choque térmico y aumentan las temperaturas debido a la entrada de oxígeno. Así como al finalizar la simulación de 600 s.

A continuación se muestran los resultados para el escenario 4, en el que el incendio tiene su origen en una colilla mal apagada que ha caído sobre una manta.

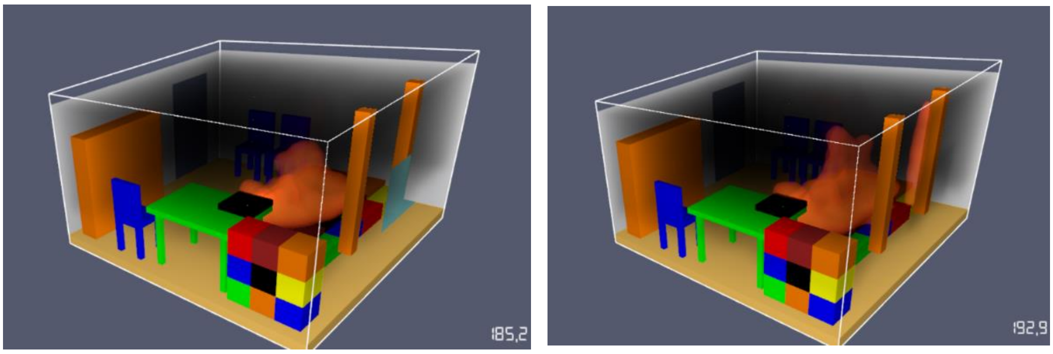

Ilustración 1. Comparación del fuego y humo antes y después de la rotura de la ventana por choque térmico

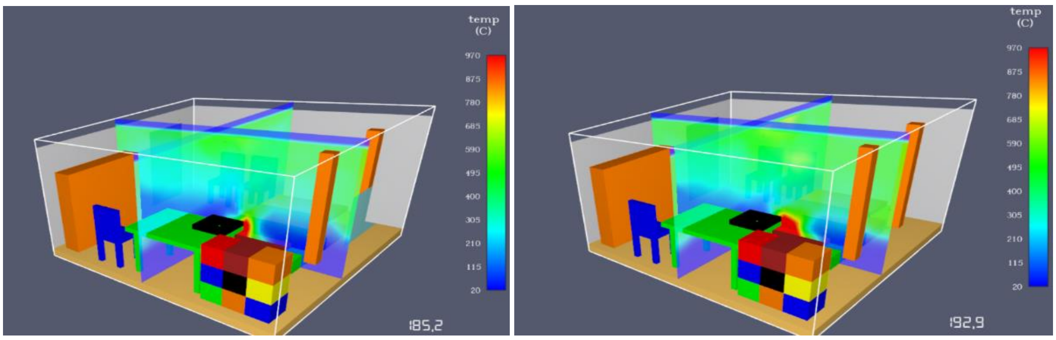

Ilustración 2. Comparación de los planos con la temperatura antes y después de la rotura por choque térmico

Con los resultados obtenidos, como las temperaturas medidas para los sensores se determinará el escenario más desfavorable. También se compararán los diferentes escenarios con el escenario 1, el cual representa una habitación en la que no se encuentran presentes factores característicos de pobreza energética, para así poder concluir si la pobreza energética tiene alguna consecuencia en el riesgo de incendio o en los efectos de este.

5. Conclusiones

Se concluye finalmente que la pobreza energética tiene un gran impacto en los incendios, ya que de todos los escenarios el único en el que el fuego no se ha propagado por completo es el escenario 1, siendo este en el que se recogen las menores temperaturas.

Hay que concluir que con una educación de calidad para las familias afectadas y con campañas para concienciar del peligro asociado a algunos hábitos como tirar las colillas al suelo se podrían reducir el número de incendios o minimizar el efecto de estos.

Aun así, se debe de concienciar de la importancia de este asunto a la sociedad, así como a los políticos y organizaciones para que reaccionen y busquen soluciones a un problema que cada vez afecta a una población mayor.

6. Referencias

[1] "Muere el bebé que se encontraba en estado crítico por el incendio en el que falleció su madre y su tío en Huelva." https://www.lasexta.com/noticias/sociedad/dos-muertos-entre-ellos-un-menor-y-un-bebe-en-estado-critico-en-un-aparatoso-incendio-en-huelva_202001075e14604c0cf2a50573f7dca8.html

[2] "Inicio - A+Familias." https://amasfamilias.com/

[3] K. B. McGrattan and G. P. Forney, "Fire dynamics simulator (version 4) :," Gaithersburg, MD, 2004. doi: 10.6028/NIST.SP.1019.

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ABSTRACT

The aim of this study is to evaluate if energy poverty is related to the risk of fire. Surveys have been carried out among families who suffer energy poverty and in collaboration with the NGO A+Familias to find out the conditions in which the households of these families are found. With the information collected, 5 scenarios have been modelled, the first one being a common room and the rest presenting each of the elements with a higher risk of fire, such as the presence of electric radiators. Software such as FDS and Smokeview were used to simulate the fires, the results were used to evaluate the spread of fire and smoke in each scenario. This has led to the conclusion that energy poverty does indeed have a high influence on the risk of fire and possible solutions to this growing problem were provided.

Keywords: Energy poverty, Fire, HRR

1. Introduction

Every year there are a large number of deaths due to fires, especially in winter. These fires are mostly suffered by families living in conditions of energy poverty, who due to the lack of resources have two options, to give up their thermal comfort or to make use of certain household appliances with a higher risk of fire associated with them, but more affordable, such as electric cookers.

One example is the one that took place in Huelva in January 2020 in which a baby, his 24-year-old mother and his 15-year-old uncle died. The fire was caused by an electric cooker, which, as previously mentioned, is one of the most common and cheapest methods of combating low temperatures in winter. [1]

2. Project definition

For the elaboration of this project, we have collaborated with the NGO A+Familias, which has provided information about the conditions in which families suffering from energy poverty and who collaborate with this NGO live. The information obtained has been used to define the scenarios that will be studied throughout the work, each of which includes one of the main dangers to which these families are subjected on a daily basis. [2]

3. Description of the model/system/tool

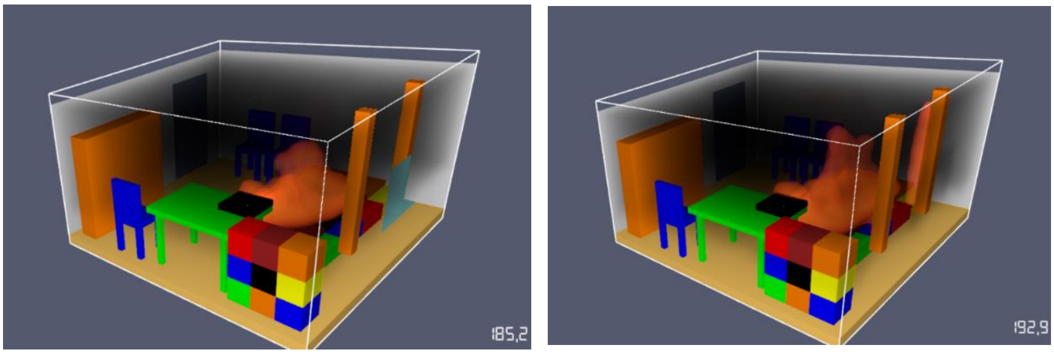
For the simulation of the fire scenarios, the FDS and Smokeview software will be used. These programmes will be used to model the rooms and simulate the first 10 minutes of the fire, as these are the most critical. The simulations will use furniture for which material properties and heat release rate (HRR) curves will have to be defined. For each piece of furniture, it will be analysed whether a constant fire is produced, i.e. if it is not consumed in the 10 minutes of fire, or if on the contrary, if it will be consumed and thus reduce its HRR over time. At the same time, the behaviour of the windows will be taken into account, which, when subjected to a certain temperature difference between the outside and the inside, will break due to thermal shock. [3]

In addition, a series of sensors will be placed in the centre and at the door of the room, as well as two planes that will divide the room into grids to measure the temperature and assess the indoor conditions.

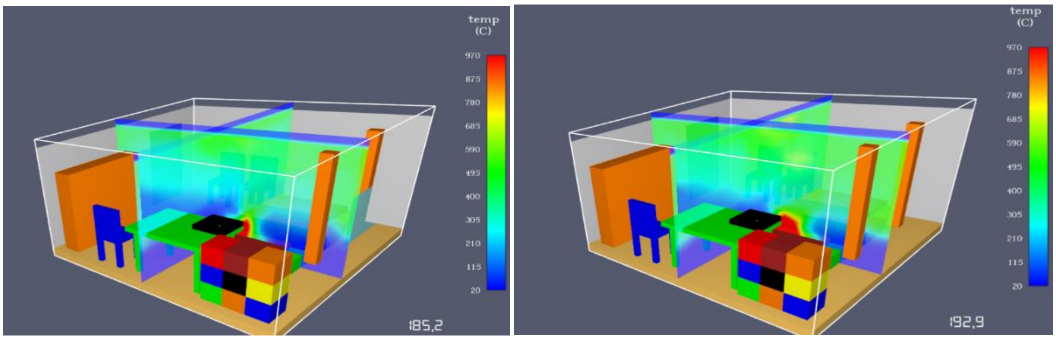
4. Results

For each scenario, the temperatures as well as the evolution of the fire and smoke will be evaluated at a series of specific moments, such as at the beginning of the fire, the instant when the window is broken by the thermal shock and the temperatures increase due to the entry of oxygen. As well as at the end of the simulation of 600 s.

The results are shown below for scenario 4, where the fire has its origin in a badly extinguished cigarette butt that has fallen on a blanket.



Ilustration 3. Comparison of fire and smoke before and after window breakage throw thermal shock



Ilustration 4. Comparison of thermal planes before and after window breakage throw thermal shock

The results obtained, such as the temperatures measured for the sensors, will be used to determine the worst case scenario. The different scenarios will also be compared with scenario 1, which represents a room in which no energy poverty factors are present, in order to conclude whether fuel poverty has any consequences on the fire risk or the effects of fire.

5. Conclusions

Finally, it is concluded that energy poverty has a great impact on fires, since of all the scenarios, the only one in which the fire has not spread completely is scenario 1, which is the one with the lowest temperatures.

It must be concluded that with quality education for affected families and campaigns to raise awareness of the dangers associated with certain habits such as throwing cigarette butts on the ground, the number of fires could be reduced or their effect minimised.

Even so, society must be made aware of the importance of this issue, as well as politicians and organisations, so that they react and seek solutions to a problem that is affecting an increasing number of people.

6. References

[1] "Baby in critical condition after fire that killed his mother and uncle in Huelva dies." https://www.lasexta.com/noticias/sociedad/dos-muertos-entre-ellos-un-menor-y-un-bebe-en-estado-critico-en-un-aparatoso-incendio-en-huelva_202001075e14604c0cf2a50573f7dca8.html

[2] "Home - A+Familias." https://amasfamilias.com/

[3] K. B. McGrattan and G. P. Forney, "Fire dynamics simulator (version 4) :," Gaithersburg, MD, 2004. doi: 10.6028/NIST.SP.1019.

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Glossary

HRR	Heat Release Rate	(W)
HRRPUA	Heat Release Rate Per Unit Area	$\left(\frac{W}{m^2}\right)$

1. Introduction

The project focuses on analysing fire safety measures in the homes of those most likely to live in energy poverty.

Every year, especially in winter, there is a large number of deaths caused by fires. The main cause is often the use of unsafe heating systems, which is the only solution these people find to fight the cold temperatures. Their low income does not allow them access to safer sources such as natural gas heating.

An example of this can be seen in the fire in the Bronx that left 19 people dead and 63 injured. This fire occurred on the 9th of January 2022 and is considered the deadliest fire in the last 30 years. The cause of the fire is known to be an electric heater.

Apart from using a heating method with a high fire risk, the inhabitants of the building ignored the fire alarm as it used to sound frequently due to the poor conditions and low maintenance of the building.[4]

Another clear example is the fire that took the life of an older woman in Reus. This woman lived alone and had no access to electricity because it had been cut off two months ago. The older woman was using candles, which was the cause of the fire.[5]

Also worth mentioning is the accident in the office in Plaza de Tetuán in Barcelona, which took the lives of a couple and their children aged one and three, caused by a badly extinguished candle.[6]

As seen in the three cases mentioned above, the causes that led to the disaster are related to energy poverty, poor maintenance and the lack of prevention measures. The aim of this TFM is to understand the situation of energy poverty in our country.

With this information, the most common scenarios provided by the NGO A+familias will be analysed and modelled using FDS, using Smokeview and Pyrosim software. Apart from these scenarios, a "*prototype*" room will be designed, with the same dimensions as the scenarios described by the NGO but with a better layout and less furniture. These better conditions will not accelerate the spread of fire, a factor that is present in the rest of the scenarios, either due to the presence of a more significant number of blankets, the storage of flammable products such as alcohol, a larger number of mattresses, etc.

This will allow us to compare the evolution of the room`s interna conditions and to be able to change the distribution of the furniture in order to obtain good habits and certain everyday products. In this way some ideas will be proposed on how to prevent certain situations in which a fire is more likely to occur, or reduce the risk.

2. Technology description

2.1. Description of the HRR Curve and Fire behaviour during a fire

First of all, before defining the numerical models to be designed, we will briefly explain what is fire and how it spreads.

Fire is a chemical reaction, it is exothermic, which means it produces heat. For a fire to take place, a fuel needs to react with oxygen to give carbon dioxide and water vapour. Flames are produced when the reaction occurs between gases, and heat and light are produced. Therefore, the energy produced in a fire depends on the properties of the fuel and the amount of oxygen , so the more oxygen there is, the more energy is emitted and the higher the temperature.[7]

The Heat Relate Rate or HRR is a variable used to measure the rate at which the fire releases energy. The HRR is one of the most important variables when describing a fire for several reasons. First, because it is the variable that stimulates the fire, and second because the rest of the variables are related to the HRR, such as the generation of smoke, gas emissions and temperature. Finally, it should be noted that the higher the HRR, the higher the risk to life, the higher the temperatures and the amount of smoke.

It is also very important to describe how a fire develops. Its behaviour depends on the amount of fuel, room ventilation, room dimensions and geometry, ambient temperature, etc.

The traditional curve for the development of a well-ventilated fire is illustrated in Figure 1.

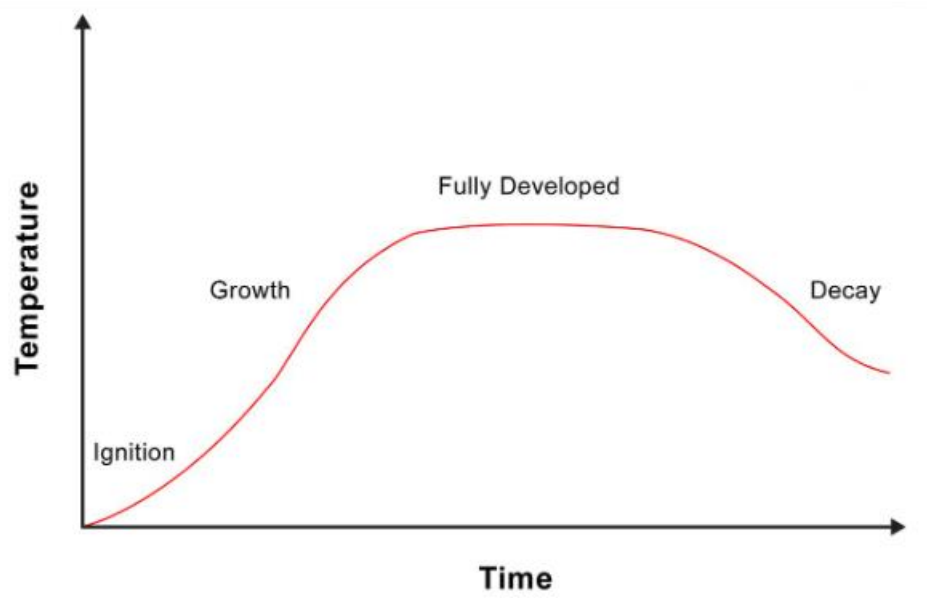

Figure 1.Traditional curve for the development of fire[7]

However, the behaviour of a room fire differs from traditional fire behaviour, since ventilation is limited. For example, if the fire starts when the windows and doors are closed.

In this case, as the fire progresses and all the oxygen is consumed, both the temperature and the heat emitted decrease. But when a door or window is opened, either because of the entry of firefighters or because the window is broken due to the poor conditions of the window, oxygen enters again. Then, the heat and temperature rise sharply again and the fire can grow again.[8]

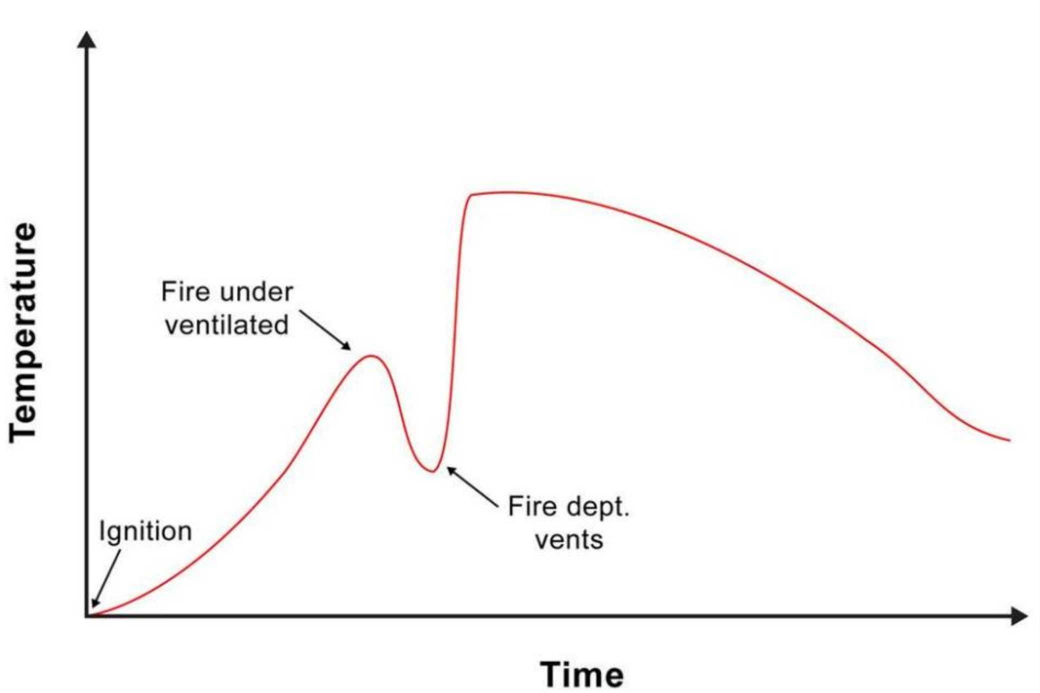

Figure 2. Curve for the development of fire in a room[7]

2.2. Tools

Two main software have been used, Fire Dynamics Simulation (FDS) and Smokeview.

FDS is a fluid dynamics software used to observe the fluid flow that occurs during a fire. It attempts to solve the Navier-Stokes equations, for low-velocity thermal fluids, and it focusing on heat and smoke during fires.

FDS has many applications, such as designing smoke treatment systems and activating smoke detectors, modelling residential enclosures. It also allows the study of the behaviour of fire and also seeks to provide a solution to the problems present in fire prevention.

This work intends to make use of the modelling of fire in enclosures. For this purpose a room must be modelled. This can be done through an fds file that will be created from the information obtained from the NGO.

The first thing to do is to define the mesh, this is a very important step that will determine the error of the model. It will be explained later what the mesh is and its importance.

In order for the software to work correctly, some parameters must be declared, such as the fuel and the reaction that originates the fire, the materials that will be used must also be defined, for which the density, conductivity and specific heat must be defined.

Then the surfaces must be described. First the surface of the "fire" must be defined, the HRRPUA and the curve must be established. Then the different surfaces that the model will use must be defined and the materials that will use these surfaces. In this case to model fire spread, it is very important to define the temperature at which the fire can propagate.

Devices will also be used. They measure the temperature of a point in the room. In this work, devices will be used to measure the temperature of the window to study when it breaks due to the temperature difference between outside and inside. These devices will also measure the temperature at different points in the room.[3]

Smokeview, on the other hand, is a program that is used to visualise the FDS results. Smokeview allows to observe smoke, temperatures and the development of the fire.[9]

As previously mentioned, the definition of the mesh is one of the most relevant points when preparing the model. The selection of a correct size is very important because this cell has to be small enough so that all the equations can be solved, and it should not be too small so that there is not a high computational cost. Therefore, the error that will be incurred in the model is associated with the cell size chosen.[10]

3. State of art

The state of the art will analyse studies that relate energy poverty to fire risk, and others that try to understand the current situation of energy poverty in our country or that seek to raise awareness of the importance of introducing human factors into fire safety.

"*The invisible US fire problem*" [11] , discusses how in the United States the demand for affordable housing sometimes exceeds the supply, so that people sometimes find other ways of living that are not regulated by law, with the problems that this involves.

Hundreds of thousands of people are homeless and millions live in slum household conditions, i.e. when a person or group of people live under one roof. These conditions lack:

- Insulation to protect them from extreme weather conditions
- Sufficient space, i.e. no more than 3 persons sharing a room
- Affordable access to water
- Access to toilets that are shared by a reasonable number of people
- Security of tenure that prevents forced evictions.

This population is the one that suffers the most from fires and has the least repercussion in the newspapers and the news. In this study, they give some definitions such as risk, or fire risk, as well as explain the types of housing depending on the associated fire risks. The report describes how the human factor is key and how they seek to connect the relationships between these factors and their environment and how they find the gaps in fire safety policies. In Figure 3, an iceberg is used to describe the dimensions of this problem.

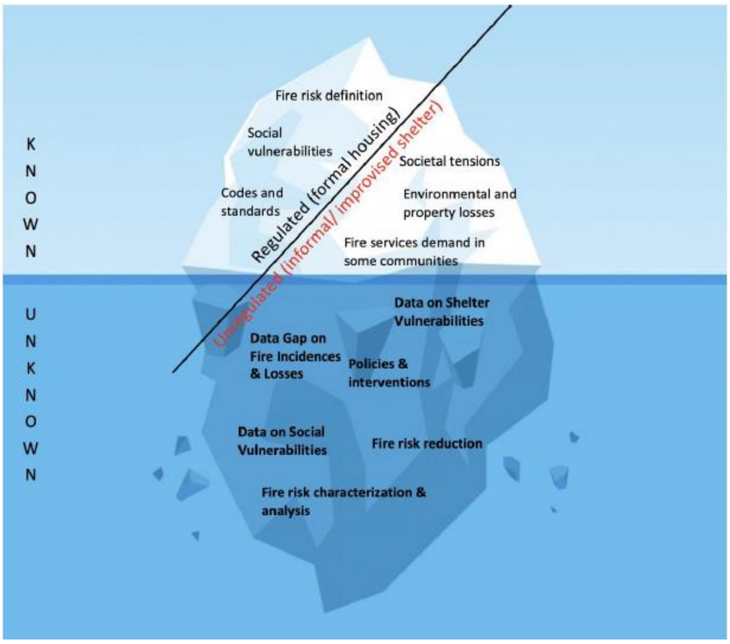

Figure 3. Problems caused by slum household conditions represented as an iceberg [11]

As seen in the figure some of the challenges that society face are:

- Fire incidents
- Housing vulnerabilities
- Intervention policies
- Social vulnerabilities
- Fire risk reduction
- Fire risk characterization and analysis

The iceberg tries to expose how most of the problems caused by slum household conditions are unregulated and completely unknown, so the government should get more involved in order to get to know most of these situations and take measures to improve the situation.

Each challenge is separated into 3 categories according to the knowledge of the inhabitant. These 3 categories are, under-maintained, under-the-radar and vacant. Furthermore, it collects the impact of each challenge.

An example of each category would be:

Category	Challenge	Impact
Under-Maintained	Landlords who do not maintain fire safety devices	Increase of risk fire
Under-The-Radar	Owners who rent a residential space without permission and fire safety	Lack of knowledge Increase of risk fire
Vacant	Occupant in vacant buildings	Increase of fire risk

Table 1. Categories of the challenges according to the knowledge of the inhabitant

In addition, this study attempts to understand all the problems associated with fire safety, listing all of them, the type of work required to solve these problems and the actions that would need to be taken.

The study concludes that the problem in the US is not solved, as homeless people are very vulnerable to fire because their housing is very unsafe and unregulated. These problems seem invisible but they exist in every city in the US. It emphasises the need for further research and investment in trying to understand and find solutions to these problems.

This can be extrapolated to our country since, as previously mentioned, fires are very common among the population with a lower income and those who live on the street.

"*Energy use strategies and implications for fire risk amongst low-income households*" [12], analyses the energy sources used in the neighbourhoods of Lwandle, Nomzano and Asanda Village, located in Cape Town, the capital of South Africa. These neighbourhoods are characterised by the low income of their residents.

Although there is universal access to electricity in Cape Town, there are frequent illegal connections to the grid. Also, the use of non-electric sources of energy is still high and poses a high risk to the inhabitants. The use of electricity is restricted by economic and physical factors. These factors are the reason why most households are forced to alternate between electric and non-electric sources, which are cheaper, but at the same time more dangerous.

Over the last 20 years, efforts have been made to reduce the number of people without access to electricity. During the last years, the percentage of the population with access to electricity has risen from 26% to 88%, in addition to the percentage of households that are illegally connected to the grid. Overall, an estimated 94% of households are connected to the grid in one way or another.

Many traditional sources are still used on a day-to-day basis, and many households alternate between electric and traditional sources, due to the fact that many households do not have a regular income and because of the low price and easy access to fuels such as paraffin.

The use of these methods goes hand in hand with a high risk of fire. In Cape Town, 16,000 fires were reported between 2009 and 2016, 47% of which were in informal dwellings. Furthermore, residents of these communities report living in a constant state of fear that they may lose their possessions. They also fear for their lives and the lives of their relatives.

According to a study by Swart and Bredenkamp([13]) one third of fires in informal dwellings are caused by candles, 56% are caused by the use of paraffin, usually by knocking over paraffin or leaving them unattended.

While non-electrical sources are usually blamed, over the last years fires caused by electrical sources have increased, mainly due to the use of old electrical appliances and negligent use of electrical appliances. In addition to the poor state of connections, especially informal ones. Between 2009 and 2015, fires caused by these sources increased by 132% in formal dwellings and by 334.5% in informal dwellings. The percentage of fires caused by electricity has increased from 10.9% in 2009 to 25% in 2015.

The study in Cape Town [12] has conducted a series of interviews and questionnaires with the inhabitants of these neighbourhoods, the dwellings of the participants have both, formal access to electricity or illegal connections.

For the study, interviews with key stakeholders were held, 60 interviews with households and 8 focus group sessions to discuss and identify problems.

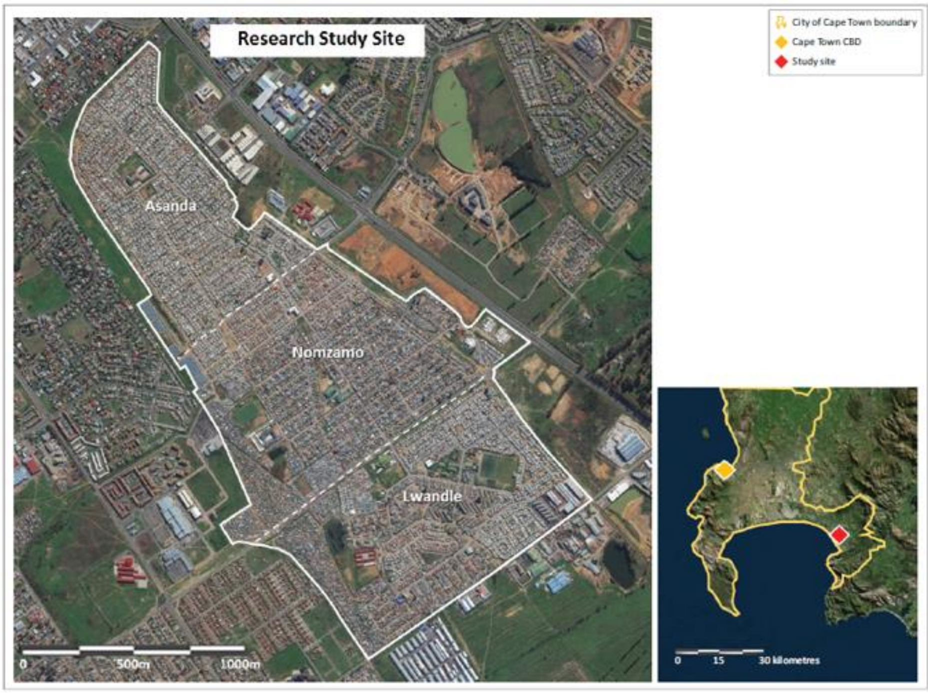

Figure 4. Study site of the research [12]

The following results were obtained:

- 97.6% have access to electricity.
- 67.2% claim to use a mixture of electrical and non-electrical sources such as candles, paraffin, gas, firewood and coal.
- Electricity has been the preferred source of energy as it is the easiest to use. Despite they prefer electricity, most of the respondents perceive it as too expensive, and have complained that landlords or companies charge high rates. Another problem of electricity use is the quality of the connection. While formal households have a professionally made connection, informal ones are often of poor quality and less safe. They tend to be too lightly loaded so as not to cause power outages or damage the connections.
- Paraffin has remained a common source among the surveyed households, as it is a versatile source and can be easily found in local shops. Cooking with paraffin serves to heat the house, whereas using electricity for cooking does not achieve this effect.
- Candles are used on a daily basis as, like paraffin, they are easily accessible and cheap and are used to light homes.
- Firewood and coal are the most often used for cooking. Many families run small businesses where they sell cooked food, and many residents use it to keep their homes warm. But although they consider it to be very efficient, they also know that its use carries a high risk of fire, as any gas leakage can cause a disaster.

The consequences of poor access to the grid increase the use of dangerous sources. According to the survey, 24.3% of households have experienced at least one fire. Most of these were small and were quickly extinguished causing little damage or injury, so they were not reported to the fire brigade.

But a few others claim to have survived fires that have destroyed their homes and forced them to build new ones, most of which have been caused by paraffin and candle. The paraffin fires are mostly caused by contaminated fuel or poor-quality fuel that leads to an explosion which make it very difficult to extinguish.

Most of these fires have been caused by accidents, not by device errors. This leads to the conclusion that the energy source it is not dangerous by itself. It is the use of the devices by humans what represents a relevant danger. Fires have also been linked to people coming home drunk, or leaving children home alone and unattended with flammable products within reach, causing them to try to cook themselves or play with fire.

Not surprisingly, fires caused by electrical sources are very low among the respondents. This confirms that they consider electricity to be the safest source, yet 19.2% of the fires that occurred to the respondents were caused by it. They mainly occur when a large number of devices are used and the network is overloaded and circuits and cables are damaged.

Respondents know that traditional methods are more dangerous and that they should use more electrical appliances, but they often do not have the option to do so due to limited resources and the high price of electricity.

The study gives a number of tips to minimise the risk such as proper ventilation to avoid the accumulation of gases if there is a leak, educating and protecting children, paying more attention while cooking and others. The work concludes that having access to electricity does not mean that people use it, mainly because of the high price of electricity.

To end, the study also concludes that the majority of those surveyed continue to live with the risk of fire despite knowing the causes and how it could be avoided. In order to minimise fires, not only should access to electricity be facilitated, but also awareness should be raised among the population, given that most fires are caused by human actions.

In "*Poverty and the risk of fire*" [14], it is discussed how today poverty is not identified as a cause of fires in an investigation, but its influence is very significant. To demonstrate this, it explains some examples of how poverty has been the main cause of fires in the United States.

Some factors that affect fires are explained, like family stability, the percentage of occupied homes, the age of the house and the ability to speak English. Examples of some of the measures that have been taken to reduce fires and their influence on the ratios are also given.

To begin with, the authors give some examples where poverty has been the main cause of fires. The first one explains how a 24 year old woman, her four children and her boyfriend occupied a house, unbeknownst to her neighbours. That house had no heating and was connected to the grid illegally. Inside the house the cables were bare and unprotected, and this is what caused the fire that took the life of the woman and her four children.

Another case is that of two brothers of 9 and 12 years old who were alone at home when the fire started in a homemade wood cooker. The house was forty years old and had no emergency exit and only one door. Only the older brother survived. According to the landlord, the house had smoke detectors, but the boy declared that he did not hear any alarm.

Poverty is not the cause of these cases, but without poverty it could perhaps have been avoided.

The study defends its position by stating that the counties with the highest poverty rate have the highest rate of fire deaths.

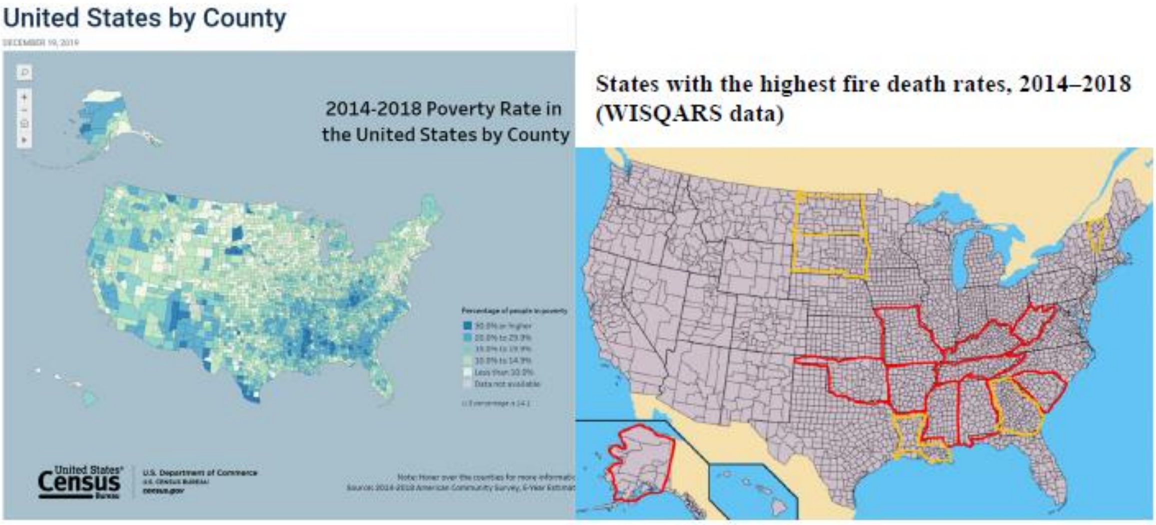

Figure 5. Comparison of poverty rate and fire deaths by county [14]

This study focuses on Cook County, Illinois. The report shows how the areas with the highest poverty rates match with the areas with the highest fire incident rates.

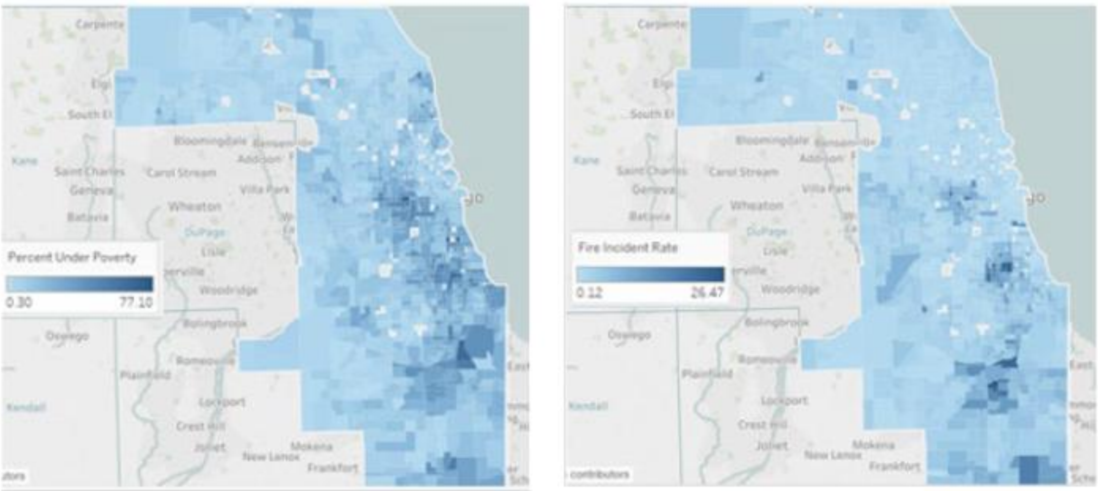

Figure 6. Poverty and home fire incident rates in Cook County, Illinois [14]

The report gives a number of examples of good practice, such as the installation of fire alarms, which are regulated (i.e. obliged to be installed by the state or by the constrictor). For example, it mentions how South Carolina launched a public education programme on the installation of fire alarms, which in 1988 was the state with the highest rate of fire deaths and the eighth highest rate of poverty. Following this programme, more than 25,000 fire alarms were installed, and by 1991 the death rate had dropped by 48%.

A similar programme was launched in Tennessee in 2012, and around 100,000 fire alarms were installed in high-risk areas, resulting in a 28% reduction in fire deaths from 2006-2010 to 2011-2015.

Finally, the work explains how fire departments cannot directly impact socio-economic changes in the communities they serve, but they can help to understand the risks they face. Investment in more initiatives such as those mentioned above is therefore necessary, as the best way to reduce these fire risks is to suppress them at an early stage, and to do so we need to tackle the social problems that go with them

The study "*Summary of energy poverty indicators in 2021*" [15]. The aim of this study is to measure energy poverty in Spain, it studies the energy bills paid by Spanish families in order to find out whether the number of households living in this situation is increasing or decreasing compared to the previous year. It describes the indicators used and calculated to measure fuel poverty in Spain and uses them to study the situation of households and to understand their expenditure and situation. The study first puts into context how the process of coming out of the pandemic has led to an energy crisis that limits household economies, especially those of lower-income families.

At the beginning of the year there were very cold temperatures, especially in Madrid where Filomena took place, but the social shield (prevents evictions and guarantees basic energy supplies) was still active so those who benefited from the "bono social" could not have their basic supplies cut off.

From June onwards, electricity prices began to rise, reaching record highs, while the price of gas on the market began to rise in the summer.

During this year the social bonds were modified and the discounts on electricity bills were increased from 25 to 60% for the vulnerable and from 40 to 70% for the severely vulnerable. Despite this, the situation for vulnerable households kept getting worse.

The study describes the indicators used. There are two types of indicators, objective and subjective: the first based on quantitative data and the second on qualitative data collected from interviews.

The indicators that best explain fuel poverty are the objective ones, which are based on household income and expenditure. The study briefly explains the main ones.

- 2M: a family suffer from energy poverty if their income is more than double the median income of all households in the country.
- M/2: they suffer from energy poverty if they spend less than the national median on their energy bills.
- Delay in bill payment
- Declared inability to keep the household at an adequate temperature
- HEP: Indicator developed by the Energy and Poverty Chair of the Universidad Pontificia de Comillas. It uses a model for energy expenditure and also uses a filter to exclude those households that have a higher income.

Each indicator captures one dimension of poverty:

There are 4 dimensions of poverty, and each dimension can be captured by one indicator:

- Disproportionate expenditure -> 2M (Twice the average percentage of energy expenditure over income)
- Insufficient expenditure-> M/2 (Spends less than half the national median on energy expenditures)
- Delayed payments (Whether there has been a delay in payment of energy bills in the last 12 months)
- Inadequate temperature (Based on winter temperature)

The report presents an indicator for each dimension and explains the calculations.

EPOV Indicator	2019	2020	2021
2M (Households)	15,20%	16,10%	15,22%
M/2 (Households)	11,50%	11,20%	10,12%
Late payments	6,60%	9,60%	9,50%
Improper temperature	7,60%	10,90%	14,27%

Table 2. EPOV indicators in Spain in 2019, 2020 and 2021

The 2M indicator decreases from 16.1% to 15.22%. This means that around 15% of Spanish households spent more than twice the national median on energy in 2021. The median value decreased from 2020 to 2021 by 0.1 %, this can be explained by the fact that household income increased which compensates for the increase in energy expenditure.

The under-spending indicator decreased from 11.2% to 10.2%, indicating that there were more households consuming below the median.

The late payment indicator remained constant, from 9.5% to 9.6%, which is worrying because although the indicator has not worsened, 10% of Spanish households are unable to pay their bills on time, and the energy situation does not bode well for the future.

The indicator of inadequate temperature is the most worrying, as it has increased from 10.9% to 14.3%. This means that 14% of the population do not have thermal comfort conditions in winter.

One particular note in this report is the HEP indicator of Hidden Energy Poverty which seeks to complement the M/2, as it introduces a filter that eliminates higher income households and uses an objective reference based on the calculation of household energy expenditure. This indicator attempts to measure households that consume less energy due to economic incapacity.

Year	2019	2020	2021
HEP	25,20%	21,10%	31,21%

Table 3.Hidden energy poverty for Spain in 2019, 2020 and 2021

The 31,21% in 2021 means that almost a third of Spanish households spend less than half of the theoretical energy expenditure needed.

Another interesting analysis of the report was the disaggregation of the HEP by autonomous communities.

Figure 7. HEP disaggregated by autonomous communities [15]

From these results it can be concluded that Islas Canarias is the region with the lowest incidence, which is obvious as it is the region with the lowest energy demand.

Andalucía, on the other hand, has the highest rate, with 19% of households, and it can be seen that the southern communities have a higher incidence than those in the north.

From the report it can be said that 2021 was a year of ups and downs, as the number of households spending disproportionately on energy costs decreased. It shows a slight improvement in all indicators except the subjective indicator of inadequate temperature and the energy poverty indicator, which worsened significantly. From these data, the study concludes that households are afraid of the bill and are therefore reducing consumption at the expense of comfort or health.

The article "Human factors in the Model of Urban Fire Spread in Madrid" [16], looks at the advantages of incorporating human and organisational factors in fire prevention especially in neighbourhoods that present a higher risk. It uses models to analyse the spread of a fire in a block of buildings in the neighbourhood of Tetuán, where the number of substandard dwellings is high.

It talks about how human and organisational factors (HOF) are fundamental to be able to improve safety in complex environments. These factors are taken into account when designing systems, technology and even materials. These factors include factors such as age, gender, ethnicity, education, etc.

These HOF are key when measuring the risk of fire in a home, since in most fires technical failures are not the only cause, as some of these factors are crucial and have high risks associated with them: for example, the use of dangerous electrical appliances, the occupancy levels of dwellings, the time taken to evacuate, etc. This study therefore seeks to highlight the advantages of including these factors in fire safety planning.

The study chooses the Tetuán neighbourhood because the characteristics of the dwellings and the population help to present a higher risk of fire. Tetuán is one of the two districts in Madrid where socio-economic conditions are considered to be lower class. It is also characterised by narrow streets, which make it difficult to access public transport or emergency services. In addition to the fact that around 8% of the people living in the district live in overcrowded homes. All these factors, together with the number of foreign inhabitants, low cultural quality and high school failure rates, mean that the conditions for the risk of fire in Tetuán is higher than in any other district in Madrid.

The block analysed has 193 dwellings and is located between Bravo Murillo, Carolinas, Topete and Alvarado. The dwellings are in poor condition, which increases the risk of fire. A number of estimates are made for the model, such as the ignition frequency or the fire load density. A Poisson distribution is used to establish the probability of ignition.

In the study, 1000 simulations were carried out. The results were compared with those accepted in Spanish society. It was observed that the damage caused by fire was greater when considering these factors, which are common among the poor population living in the district. The study emphasises that fire spread maps, apart from being used for risk analysis, should also be used to identify areas that are associated with greater danger. It concludes that lifestyle influences the spread of fire due to the conditions in which they live, such as the increased use of blankets to minimise heating costs or the use of fires for cooking.

Finally, the work reflects that human factors should be included in fire safety analyses, and training should be implemented to improve the safety culture of this most vulnerable population. These measures could help to understand the risks associated with their habits and the best guidelines for evacuating their homes.

It should be noted that several of the previously mentioned articles relate energy poverty to fire risk by using data or statistics, and propose expensive actions, limiting themselves to raising awareness and moving the problem on to third parties, such as the government, security departments, etc.

4. Work definition

4.1. Justification

As seen in the previous section, some of the studies describe and analyse the current energy poverty situation in Spain, providing data and calculations to analyse the situation. In another study, fires are simulated in a neighbourhood where the population has low incomes. There are many factors that are characteristic to energy poverty and that are associated with high fire risk. But like the previous studies mentioned in the previous section, they limit themselves to providing solutions and raising the reader's awareness.

This work, apart from relating energy poverty with fire risk, seeks to analyse what protection measures are available to the most disadvantaged population that suffers of energy poverty. To better understand how fire can have a higher impact on this population, different scenarios are simulated to better understand which are the main causes of fires or the situations associated with a greater risk of fire. The aim is to provide a series of simple guidelines in order to raise their awareness and thus facilitate the necessary training to reduce the risk of fire as much as possible.

4.2. Data collection

In this work, in collaboration with the Service Learning students, surveys were carried out with the families they visited. As they fitted the energy poverty profile. Some questions were asked to find out whether the families smoked indoors, what methods they used to heat the house in winter, whether they stored flammable products in their rooms and, finally, whether they had witnessed a fire, either in their own house or in a neighbour's house. Questions can be seen in [8.7].

Of those surveyed, it is worth noting that one family had a fire in their kitchen and that one member of most of the families smoked indoors. The aim of these surveys was to find a target family that might be more vulnerable so that we could visit their home and model their rooms. But in the end, this was not possible. Finally, we collaborated with the NGO A+familias, an association that helps vulnerable families.

A meeting was held with a social worker from the organisation who provided information on the state and conditions of the rooms of the families she was assisting. It was commented that families of 4 to 5 people usually live in these rooms. Most of them share a flat and do not have a contract, so the landlords take advantage of the situation and the houses are usually in a bad state of repair.

In other cases, landlords divide the rooms with cardboard walls, in order to increase the number of tenants, obtaining a higher profit.

What they all have in common is the poor condition of the house, because most of them are old buildings and the landlords do not care about the condition of the household.

In addition, due to the large number of people living in the rooms, there are a large number of mattresses and cardboard boxes to store all the family's clothes. On the one hand, in winter it insulates the heat worse, so it is colder inside. To avoid this, families make use of a greater number of sheets or electric radiators, with the danger that this entails. In addition, as more air enters, there is more oxygen, which favours the spread of a fire once it has occurred.

It was also mentioned that some families use alcohol or other flammable products for heating in the winter months. They usually pour the alcohol into a metal container and set it on fire, making a kind of bonfire. Apart from the risk this entails, this means that they store these products in the room, so in the event of a fire this helps the fire to spread.

In addition, it is very common in these families to smoke indoors or in front of the children. In addition to this, they are also in the habit of throwing cigarette butts on the floor and leaving lighters in places that are easily accessible to children, which increases the likelihood of a fire starting.

It should also be added that most of these families are made up of the mother and the children, so that often while the mother is cooking she has to look after the children, which has sometimes led to carelessness that has led to a fire.

All these data obtained will be used when modelling the rooms, to simulate where fires originate, and what products or materials will be present in the room.

5. Developed Models

5.1. Model Definition

Fire spread in FDS can be done in three ways: the first would be through pyrolysis which was discarded for this work since the models are very complex and requires a powerful CPU; the second would be through a known spread rate, in which the fire spreads circularly simultaneously, but this method does not take into account the properties of the materials or the temperatures at which it starts to burn: and the third is based in the ignition temperature. The problem with this method is that it does not consider radiation and also that the properties of the material do not change throughout the fire as in pyrolysis, but the models are simpler. These are the reasons, this last way will be used.

According to a recreation of a fire caused by a badly extinguished cigarette butt in a living room with several sofas, wooden tables and chairs and other elements such as curtains and blankets, elements similar to those present in our scenarios, the time elapsed from the start of the fire until the flames occupy the entire room is 5 minutes[17]. For this work, the fire will be simulated for ten minutes to study in greater depth the differences between the model room and the rest of the rooms that suffer from energy poverty.

In order to model the rooms, the properties of each material and the HRRPUA curves for each of the pieces of furniture had to be found, which can be seen in the appendix[8.2].

Then, with each of the furniture curves, their weights and the heats of combustion of each material, it has been studied whether during the simulation time the furniture will have a constant fire or a variable fire. The constant fire is the one that after the growth phase maintains a constant HRR. This is due to the fact that not all the material is consumed during the simulation time. If the material is considered to be consumed, the HRR starts to decrease. The different HRR curves used are described in the annex [8.3].

The calculation is simple, multiply the weight of the piece of furniture by the heat of combustion and divide it by the HRR. If the time obtained is greater than 600 seconds, the fire for this piece of furniture is considered to be constant, otherwise it is considered to be variable.

$$Time\ of\ consumption = \frac{Weight \cdot Heat\ of\ combustion}{HRR_{Max}}$$

The only element for which the fire will be considered to be variable are the blankets, the rest will have constant fire.

The tables with the heats of combustion and weights can be found in the annex [8.4].

All the rooms designed for the work will be 5 mx5 m (25 m^2) as these are the standard measurements that were discussed in the meetings with the NGO. In addition, each room will have a door and a window and the door will remain open while the window will remain closed.

It will also be taken into account for the simulation that the glass breaks due to thermal shock caused by the difference in temperature between inside and outside. For the simulation windows with tempered glass that withstand temperature differences of up to 200 ° C are considered. If it is assumed an ambient temperature of 20 ° C, it will break when it reaches 220 ° C. [18]

For the work, models will be made for 5 scenarios

1. Room in good condition, not overloaded with items.
2. Room overloaded, fire caused by an electrical overload setting a curtain on fire.
3. Room overloaded, fire caused by an electric cooker.
4. Room overloaded, fire caused by burning alcohol to heat the room.
5. Room overloaded: fire caused by an improperly extinguished cigarette.

Each scenario reflects an important risk that these families face in their daily lives, the causes of these fires can be energy poverty or bad habits, but in the latter cases energy poverty facilitates the spread of the fire.

The first two scenarios have the same cause of fire, but it should be noted that in scenario two the conditions of the electrical installation are worse. This is due to the fact that in many cases the installations are very old and are not subject to any type of revision. Scenario 3 includes the case when families cannot use heating to achieve thermal comfort so they resort to methods such as cookers that have a high risk of fire that can even increase when children are present who may be less careful. Scenario 4 represents the main risk for families who instead of using cookers use containers and fill them with alcohol to light and heat. Often the fire occurs when more alcohol is poured into the container, as it can get out of control, and often it is a child who carries out this process. The last scenario is in which the family uses many blankets for heating and there is also a smoker, and as mentioned above, cigarette butts are thrown on the floor. This increases the probability that when all the mattresses are on the floor, a badly extinguished cigarette butt falls on one of the blankets and sets the room on fire.

It should be noted that for all scenarios, two planes have been placed to divide the room into grids in order to observe the evolution of the temperatures. Sensors have been placed every 0.4 m along the Z-axis in the centre of the room and at the door to evaluate the behaviour of the temperature throughout the simulation.

Scenario 1:

This scenario shows a standard room. The fire is caused by an electrical overload in the cables under the curtains.

The room has the following elements:

- One chest of drawers
- One wardrobe
- One wooden bed base
- One mattress
- One bedside table
- One table
- One wooden chair
- Two polyester curtains

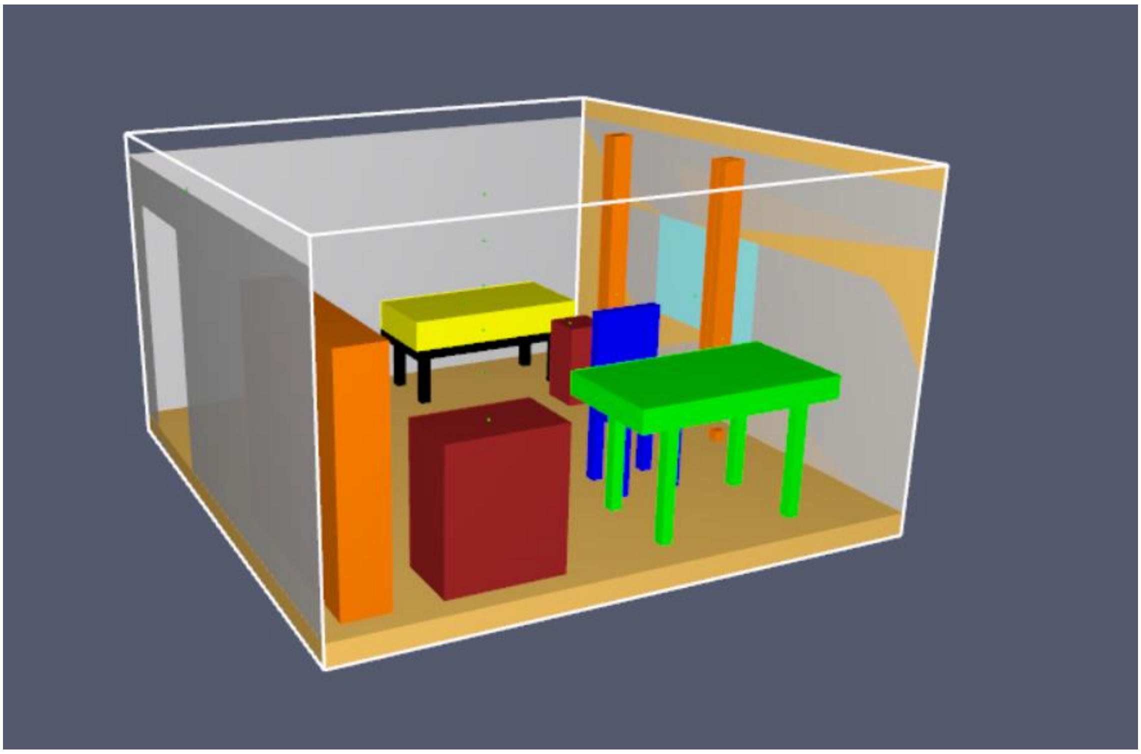

Figure 8.Room layout 1

Scenario 2:

In this scenario the fire would be caused by an electrical overload in a cable under the curtains.

The room has the following elements:

- One wardrobe
- One table
- Four chairs
- Nine Cardboard boxes with clothes inside
- Four mattresses
- Two curtains
- Two blankets on the table

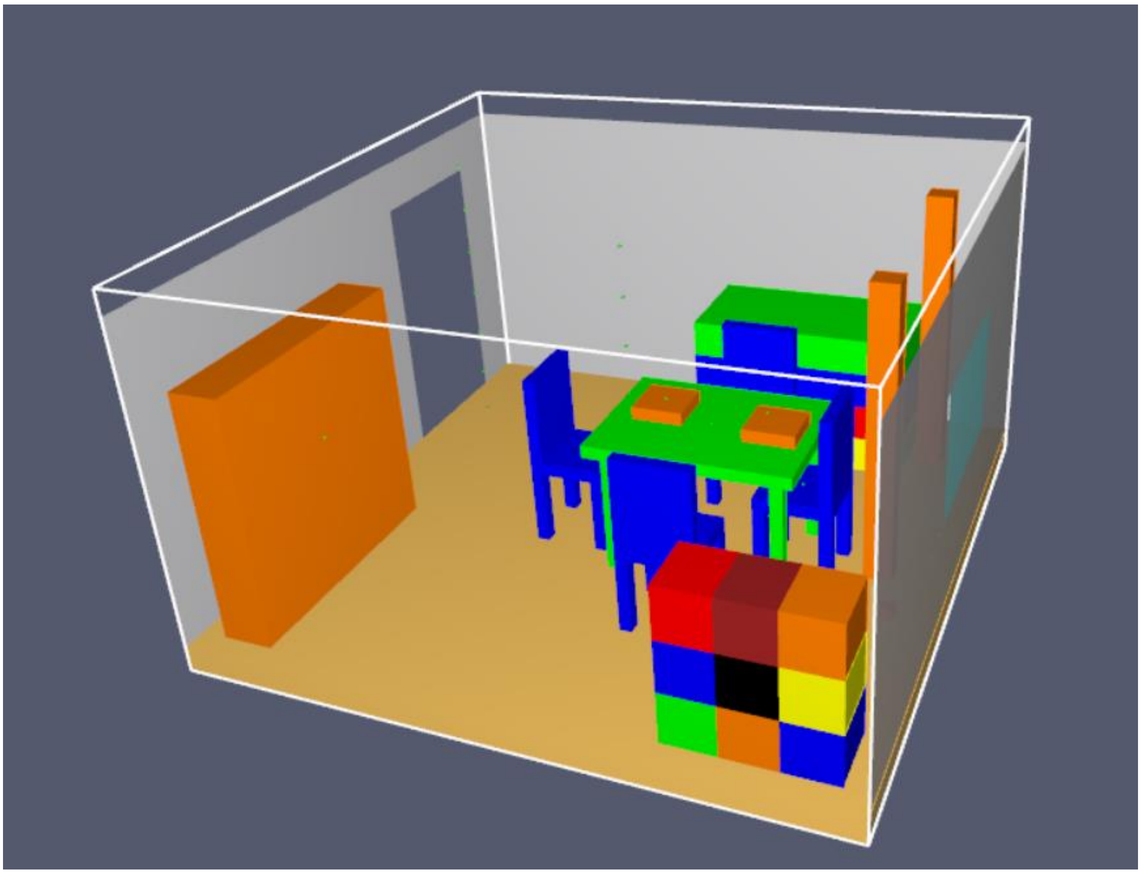

Figure 9. Room layout 2

Scenario 3:

In this scenario the fire is caused by an electric cooker coming into contact with the table skirt.

The room has the following elements:

- One wardrobe
- One table
- One electric radiator
- One table skirt
- Three chairs
- Nine cardboard boxes with clothes inside
- Four mattresses
- Two curtains
- Two blankets on top of the bed

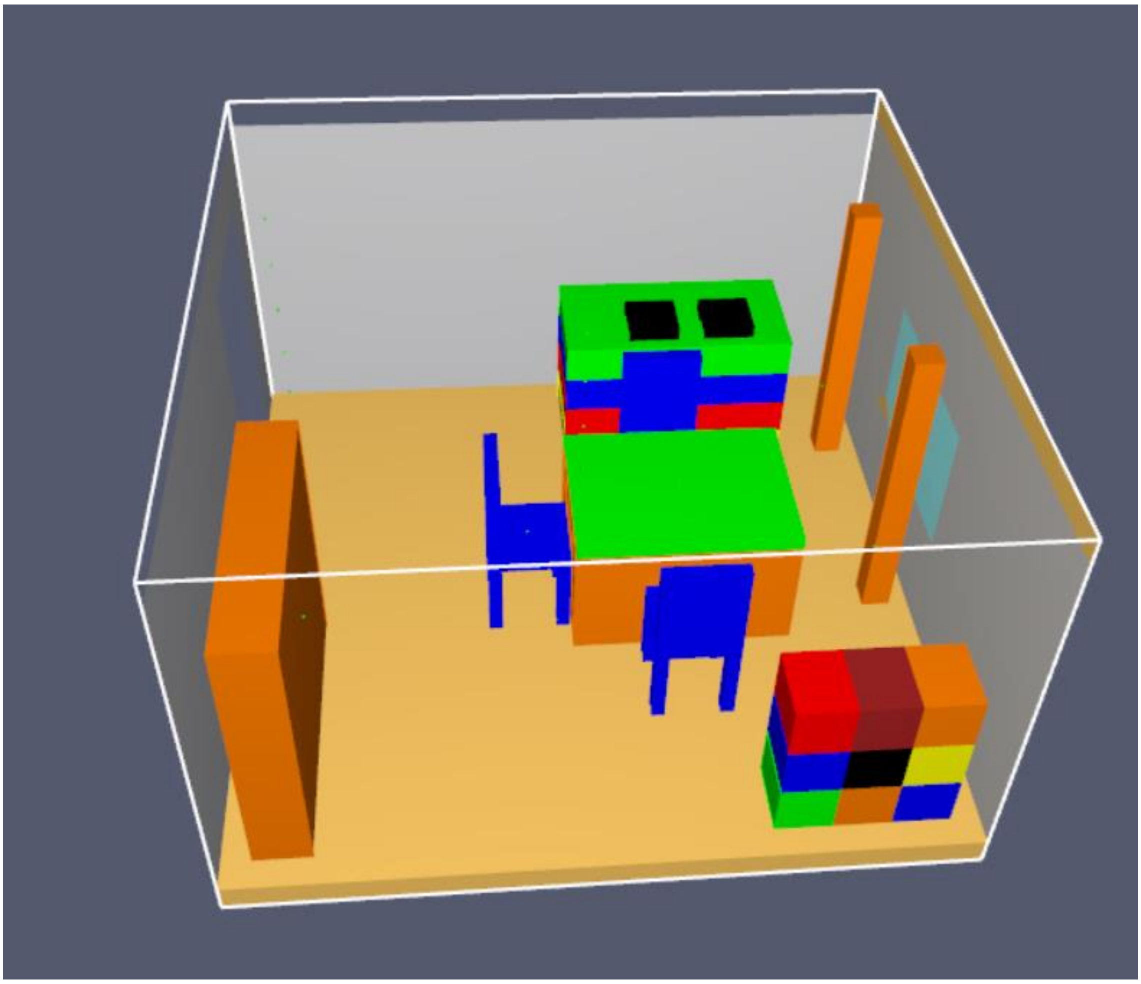

Figure 10. Room layout 3

Scenario 4:

The fire is caused by alcohol burning in a container when it gets out of control and the flame comes into contact with the mattresses.

The room has the following elements:

- One wardrobe
- One table
- One bowl with alcohol
- One table skirt
- Three chairs
- Nine cardboard boxes with clothes inside
- Four mattresses
- Two curtains
- Two blankets on top of the bed

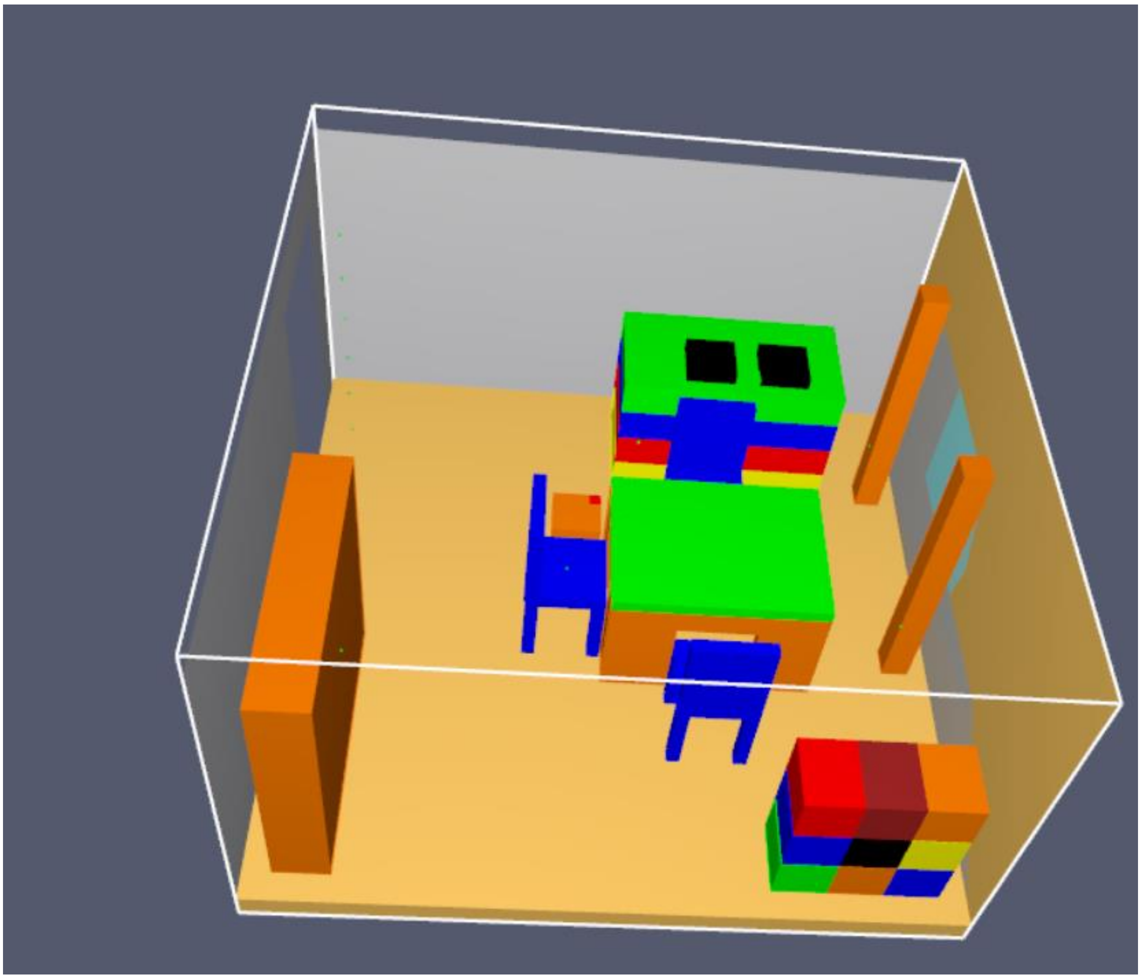

Figure 11. Room layout 4

Scenario 5:

In this case, the fire was caused by a badly extinguished cigarette butt which, when thrown on the floor, came into contact with one of the blankets.

The room has the following elements:

- One wardrobe
- One table
- Three chairs
- Nine cardboard boxes with clothes inside
- Four mattresses
- Two curtains
- Four blankets on top of the beds and one on top of the table

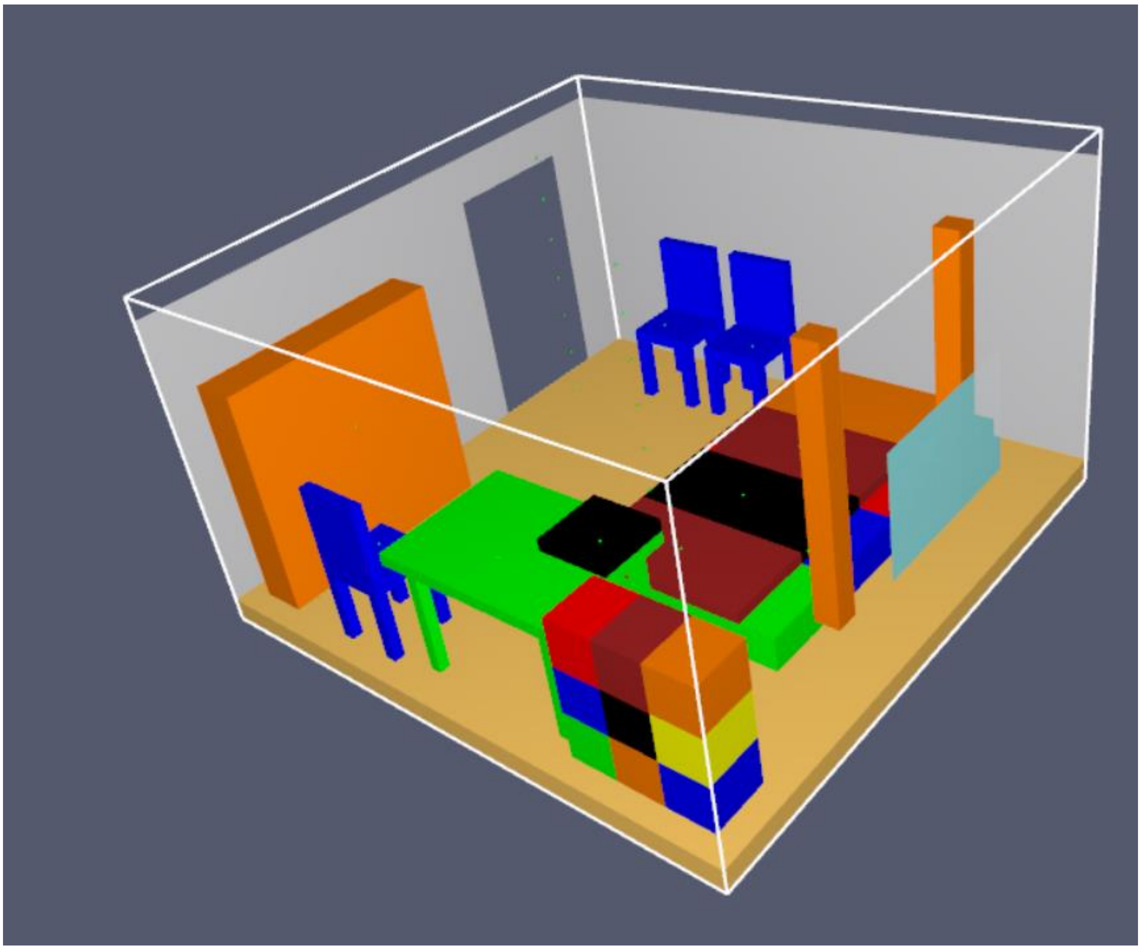

Figure 12. Room layout 5

5.2. Model Results

Once all the scenarios have been designed, the fires were simulated to study in which scenario the highest temperatures were reached or in which the fire spread at a higher speed, with the aim of identifying the scenario with the most unfavourable conditions and to check whether energy poverty and fire risk are indeed related.

Scenario 1:

The image below(Figure 13) shows where the origin of fire takes place.

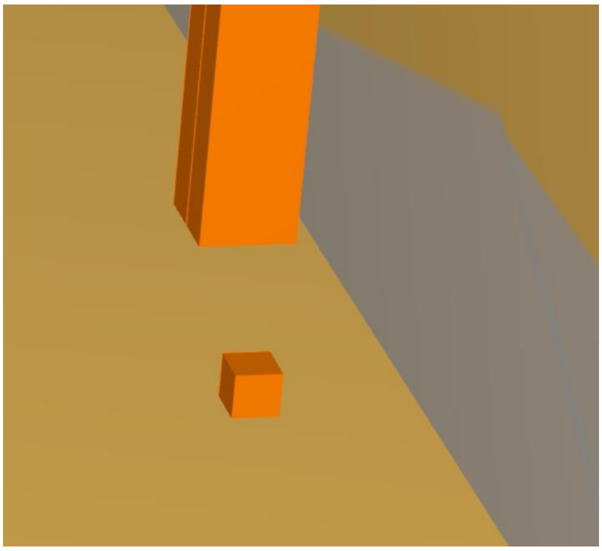

Figure 13. Cable section to be overloaded

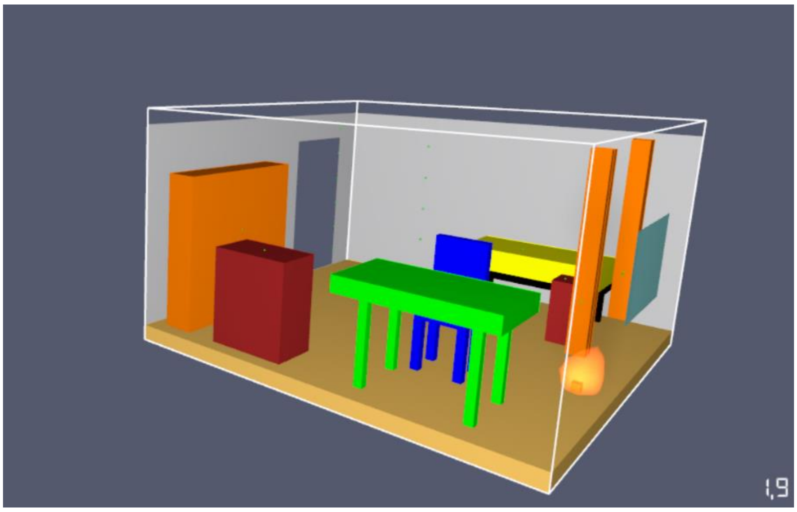

Figure 14. Start of fire for scenario 1

Figure 14 shows the start of the fire, while Figure 15 shows both the fire and the smoke at 600 seconds, as well as the two planes with the temperatures at that instant.

It can be seen from the tables(Table 4 and Table 5) how at instant 0 the ambient temperature is 20°C. Subsequently when the fire starts the curtain starts to burn and only spreads to the curtain on the right. It has not spread to any other element such as the bed or the table. This is due to the fact that the temperature was not high enough for the fire to spread to the other elements, mainly because the elements present have a very high ignition temperature, which makes it difficult for the fire to spread.

This can be seen in Figure 15 and the tables(Table 4 and Table 5), where the temperatures for heights below 1.6 metres do not exceed 160 °C, far from the 350 °C necessary to spread to wooden elements such as the table or chair.

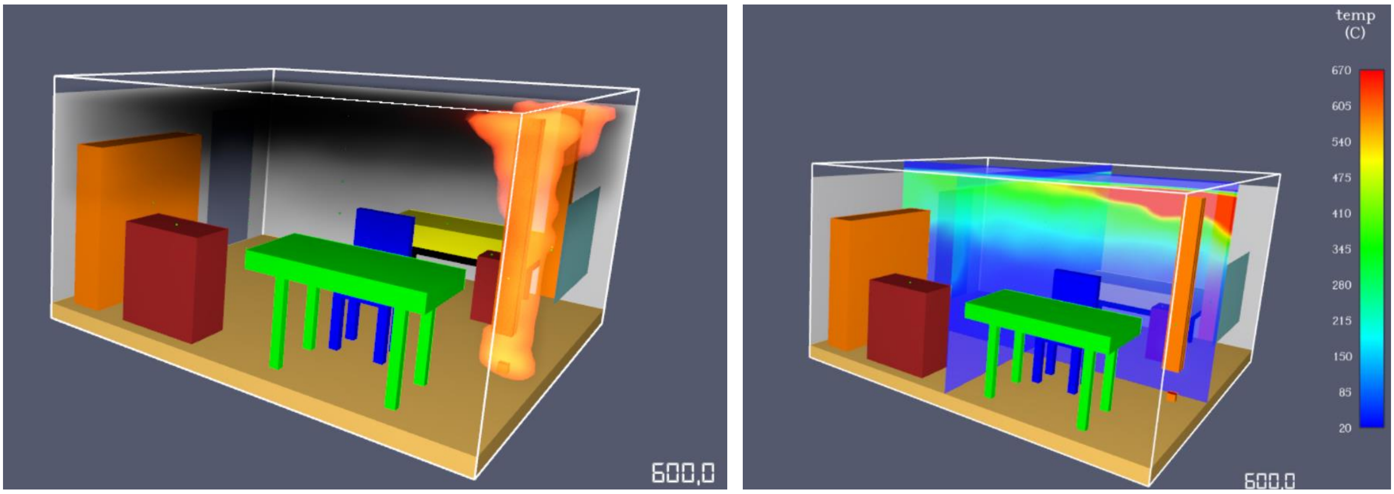

Figure 15. State of the fire in the second 600.

The tables below show the temperatures in the centre of the room and at the door every 0.4 m in height. It can be seen how there is an increase in temperatures from the second 450 to 500, this is due to the fact that it is in this time interval that the fire spreads to the second curtain, which means an increase in temperatures, but it is not high enough for the rest of the furniture to start to burn.

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	20	21	26	40	55	64
100	21	21	22	35	59	80	89
150	22	23	24	33	95	139	174
200	23	25	25	34	103	178	251
250	24	25	26	31	110	180	293
300	22	26	27	36	109	181	308
350	23	26	28	33	110	169	268
400	23	26	27	35	116	189	284
450	24	27	29	36	102	176	338
500	26	29	31	40	128	188	389
550	24	28	32	43	129	206	389
600	25	29	31	46	130	198	425

Table 4. Temperature in the center of the room 1

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	20	20	24	43	50	55
100	20	20	20	29	58	78	74
150	20	23	24	30	86	138	140
200	20	24	26	44	116	177	201
250	20	23	26	35	123	189	221
300	20	20	28	43	109	188	223
350	20	20	32	46	113	176	221
400	20	20	31	50	128	170	222
450	20	21	26	40	127	205	242
500	20	22	28	42	137	233	294
550	20	21	29	45	158	223	319
600	20	20	25	45	153	254	291

Table 5. Temperature at the door in room 1

Scenario 2:

In scenario 2 the cause of the fire is identical to scenario 1, due to an overloaded cable under the curtains, except that in this scenario the likelihood of fire is much higher due to the poor state of the electrical installations in the homes of these families.

Fire origin(Figure 16):

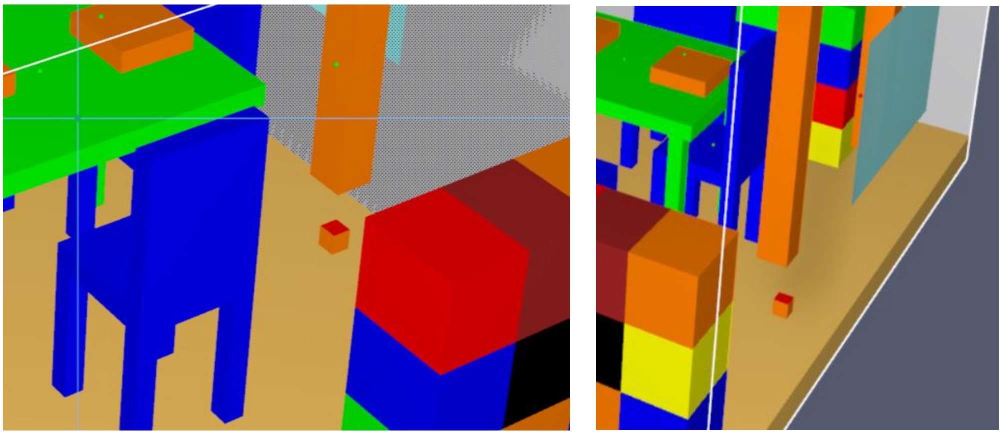

Figure 16. Cable section to be overloaded

Room at the time of the fire's outbreak (Figure 17):

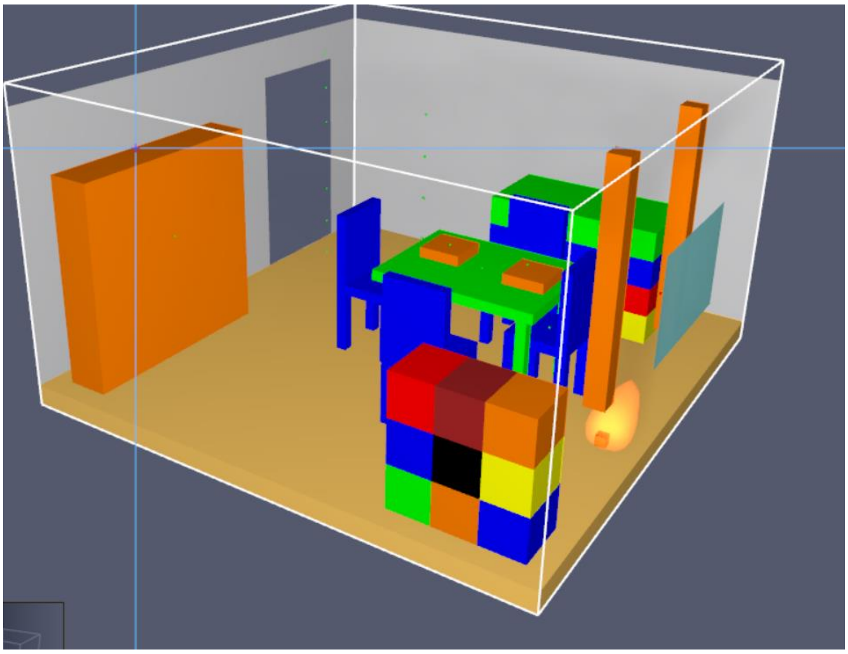

Figure 17. Start of fire for scenario 2

The fire starts in the curtain on the left and then spreads to the boxes of clothes and the curtain on the right, and finally after the breakage of the window it spreads to the chairs and the table.

It is worth noting the moment when the window breaks due to the difference in temperature.

Below is a photo of the state of the fire and smoke before and after the window breakage, shown in light blue in the photo on the left (Figure 18):

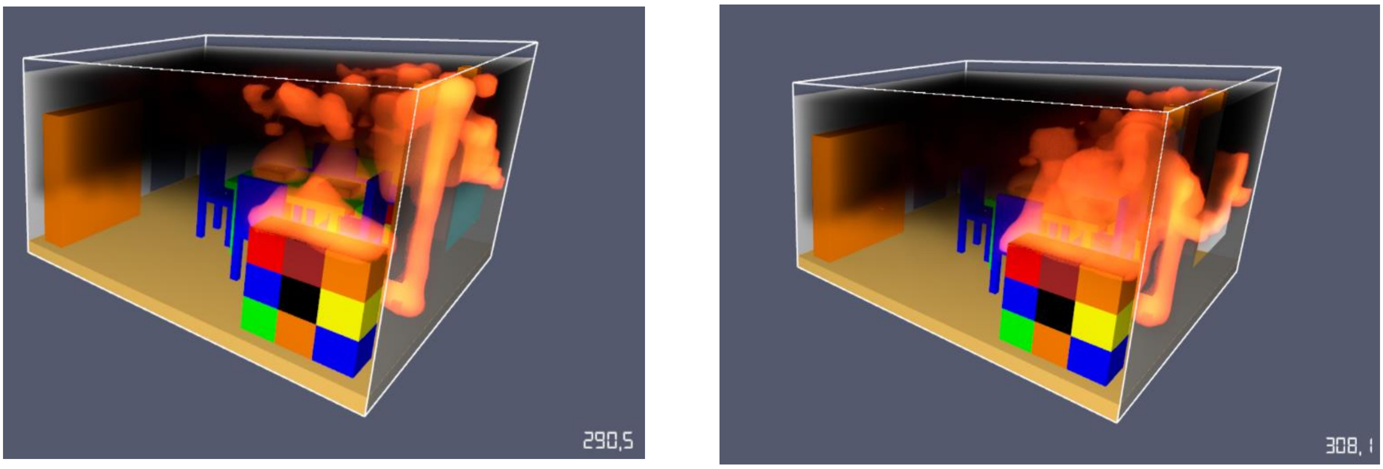

Figure 18. State of the fire before and after the window breakage for room 2

The temperatures for these times can also be seen in Figure 19:

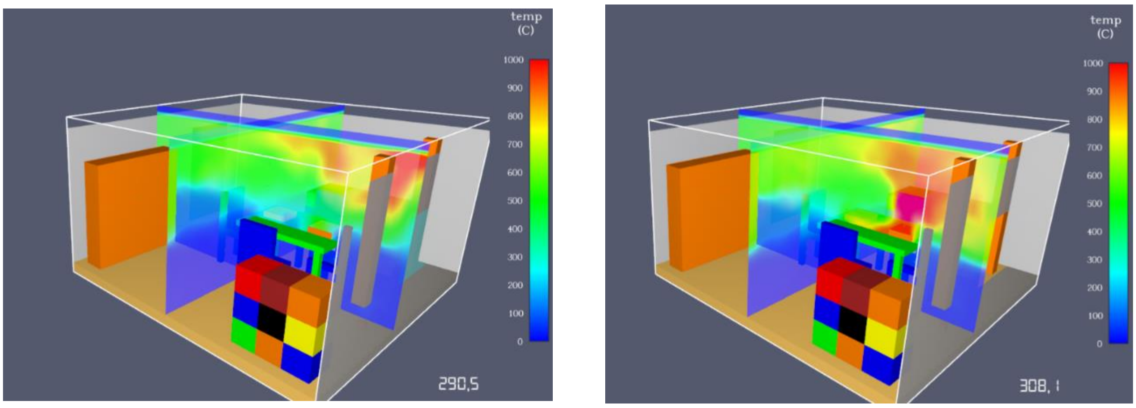

Figure 19. Temperature before and after the window breakage for room 2

Finally, the smoke and temperatures can be observed at the end of the simulation, it can be seen how the temperatures are very high, this is due to the fact that most of the furniture is still on fire, and the smoke occupies the whole room(Figure 20).

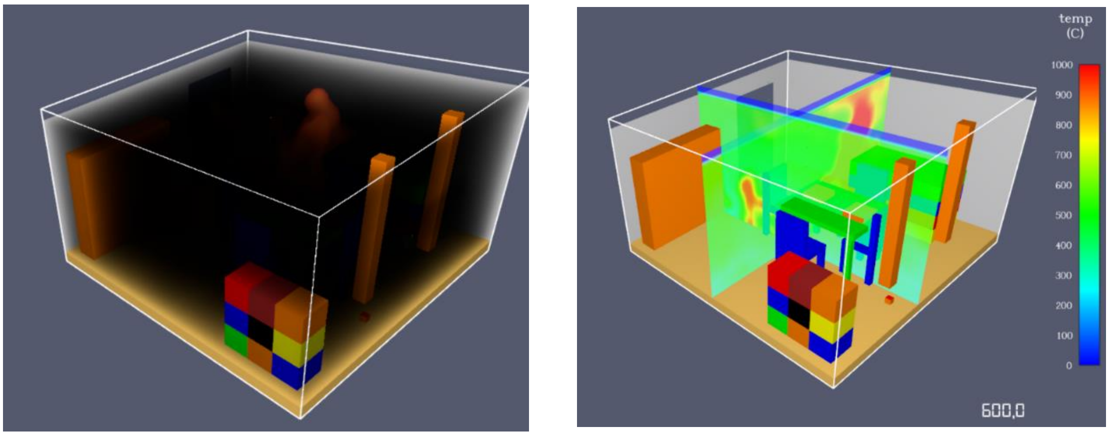

Figure 20. State of the fire at the end of the simulation in room 2

The impact of the window breakage on the fire is best seen in the tables showing the temperatures of the sensors in the centre of the room and at the door. The window breaks at second 292.5. A huge change in temperatures between second 250 and 300 are observed, just after the window has broken, mainly due to the influx of oxygen which accelerates combustion.

The high temperatures in the centre of the room at 1.2 m are due to the fact that this is the height of the table, and it increases dramatically from second 250 to 300, at the same time of the breaking of the window and the ignition of the table. The decrease in this temperature is due to the fact that the fire stabilises after the addition of oxygen due to the absence of the window, as explained in previous sections.

The high temperature at 2.4 metres is due to the smoke that is produced throughout the fire, both in the centre of the room and at the door.(Table 6)

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	20	21	32	65	101	161
100	22	23	23	34	108	216	311
150	22	24	25	42	116	189	330
200	23	25	26	42	122	235	378
250	25	30	33	54	239	302	384
300	29	39	56	508	419	494	611
350	196	338	429	782	717	756	670
400	298	527	801	436	490	569	615
450	514	557	459	442	457	498	597
500	571	1020	689	437	438	471	617
550	351	436	431	432	466	511	619
600	462	793	459	412	437	471	592

Table 6. Temperature in the center of the room 2

However, as can be seen in the Table 7, at the door the temperature increase occurs around the second 200, which is when the bed next to the door starts to burn.

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	20	20	26	88	105	114
100	20	21	26	39	119	217	255
150	20	22	23	34	111	213	253
200	20	20	23	36	122	239	308
250	20	25	28	52	236	346	445
300	20	31	83	256	354	453	526
350	65	184	277	561	535	566	532
400	167	748	559	551	555	527	589
450	90	756	786	771	618	615	577
500	27	369	852	535	525	572	571
550	44	438	529	806	564	606	616
600	36	188	776	657	566	603	618

Table 7. Temperatures at the door in room 2

Scenario 3:

In this scenario the fire originates in an electric cooker when it comes into contact with the table skirt. (Figure 21)

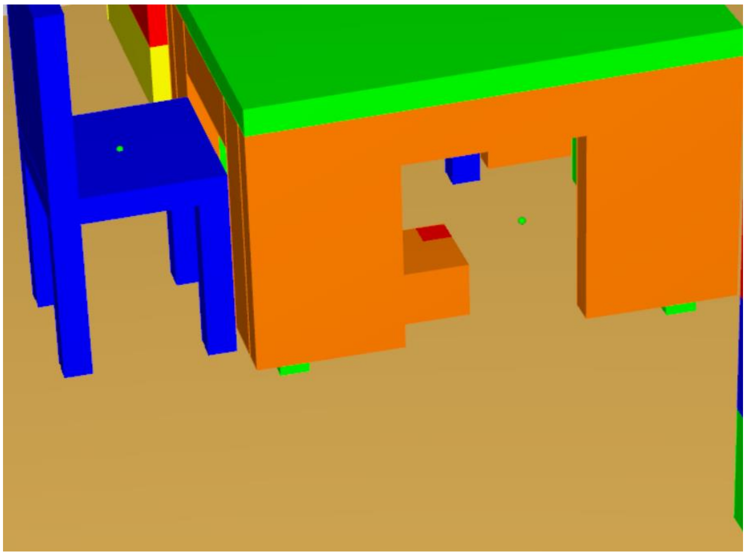

Figure 21. Start of fire for scenario 3

The fire originates in the heater, and spreads to the table skirt and then to the curtains. The window is broken due to the high temperatures. This happens on the second 130, and due to the increased temperatures the fire spreads to the chairs and table.(Figure 22)

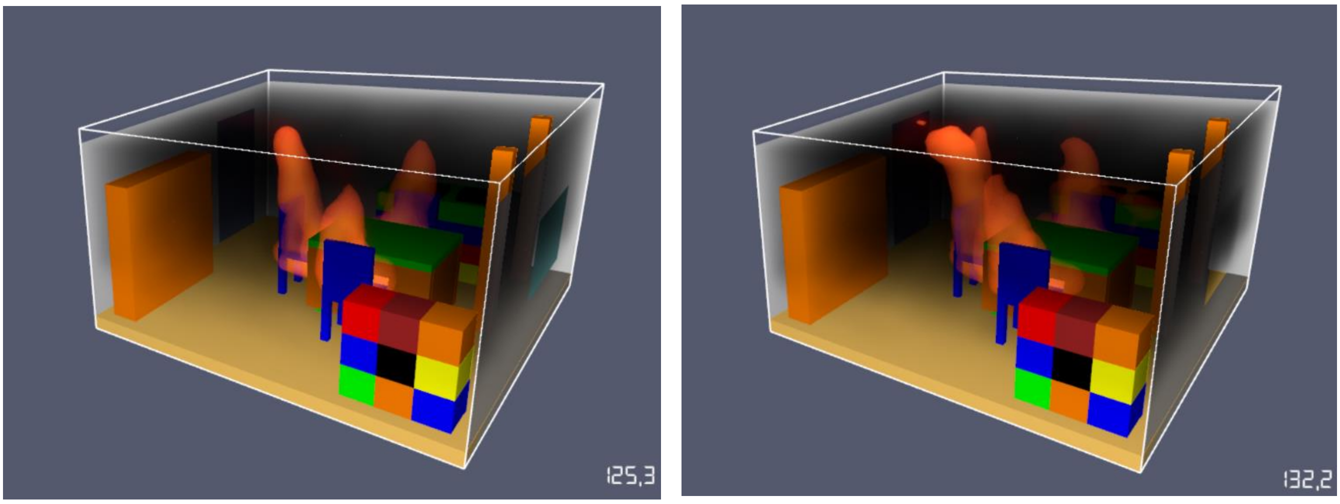

Figure 22. State of the fire before and after the window breakage for room 3

This temperature increase can be clearly seen in the temperature planes, where it can be seen that after glass breakage the temperatures increase downwards on the vertical axis.(Figure 23)

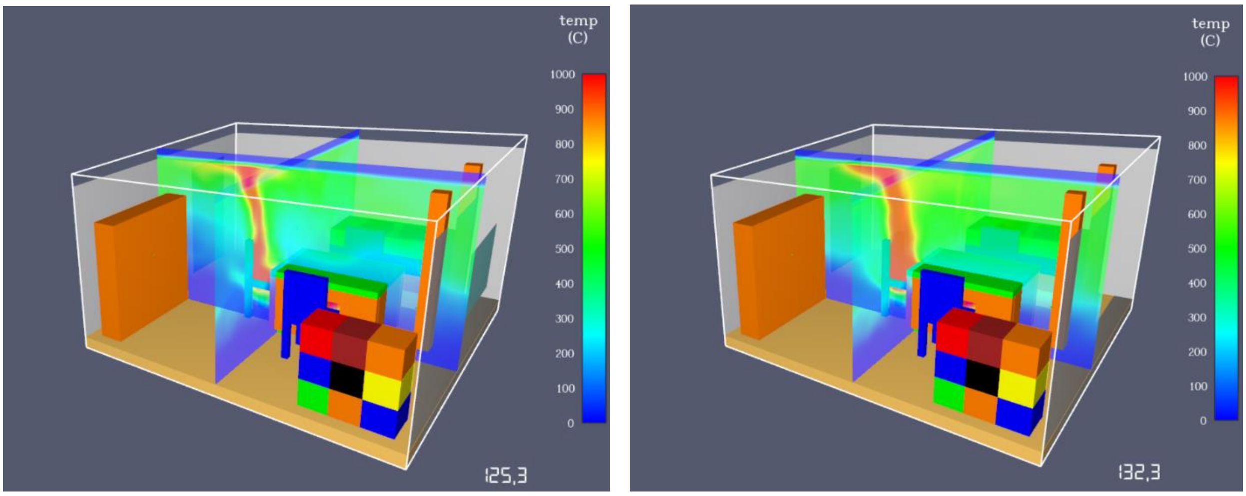

Figure 23. Temperature before and after the window breakage for room 3

You can see how the fire continues at the end of the simulation and as in the previous scenario the room is full of smoke.(Figure 24)

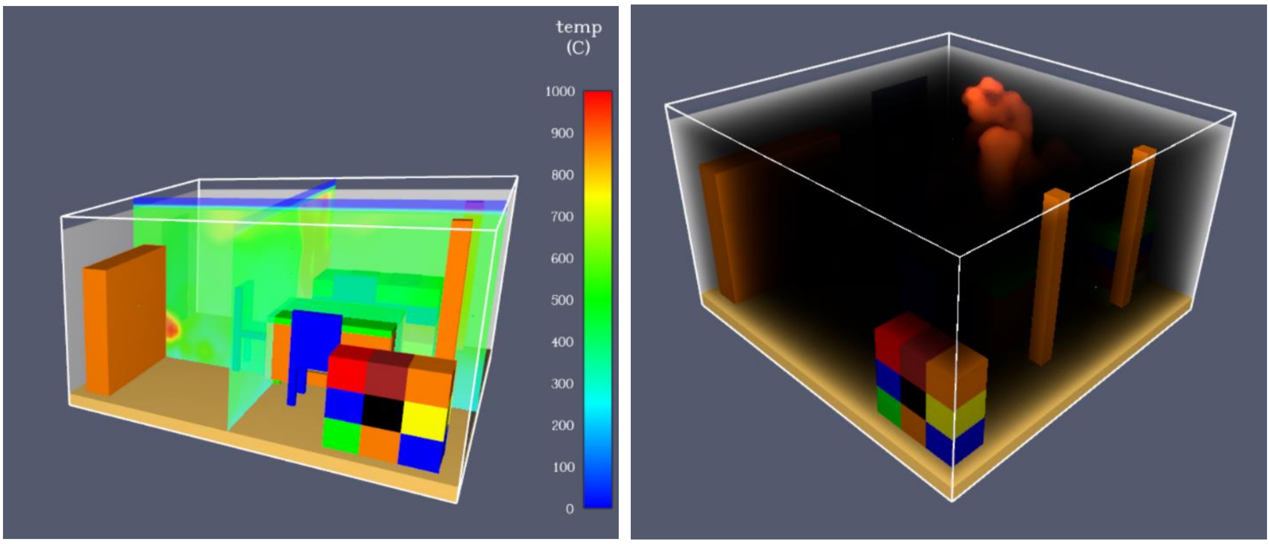

Figure 24. State of the fire at the end of the simulation in room 3

As previously mentioned, the breakage of the window occurs around the second 130, this fire is more accelerated than the previous one since the fire starts under the table and the table skirt begins to burn, the drop in temperature is due to the fact that the fire stabilises after the breakage of the window and also because the table skirt has been consumed. In the tables(Table 8 and Table 9) you can see the effect of the entry of oxygen, which means a sharp rise in temperatures from the 100th to the 150th second, especially in the centre of the room, where the table and chairs are located, which, as explained above, start to burn at this moment.

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	22	121	197	34	41	45	51
100	24	75	846	36	48	68	81
150	918	924	838	772	777	793	754
200	645	545	720	549	573	764	734
250	667	794	730	405	451	488	607
300	972	679	669	458	488	511	586
350	607	418	444	413	447	493	687
400	552	395	371	414	454	507	621
450	286	358	343	395	449	485	624
500	361	362	401	433	465	555	661
550	471	358	379	416	477	482	575
600	309	349	409	411	425	485	650

Table 8. Temperature in the center of the room 3

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	20	26	33	37	40	47
100	20	21	37	37	46	48	52
150	41	228	257	424	507	582	632
200	61	433	699	762	634	553	596
250	37	269	464	683	612	572	585
300	96	787	700	699	589	594	564
350	50	433	669	533	547	630	636
400	70	591	748	703	565	608	666
450	62	262	790	752	614	729	695
500	40	89	923	855	609	579	532
550	40	417	701	748	590	604	663
600	107	625	672	820	698	627	637

Table 9. Temperature at the door in room 3

Scenario 4:

In this scenario the fire is caused to the burning of alcohol in a container to heat the room, the fire would originate when the container is refilled while it still contains burning alcohol, which increases the flame and comes into contact with the mattresses and the table skirt next to them.

The image below shows where the fire would start(Figure 25)

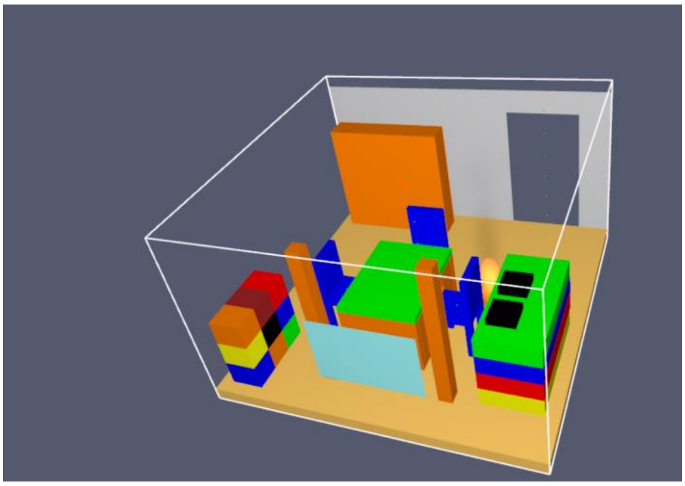

Figure 25. Start of fire for scenario 4

As mentioned above, the fire started in the mattresses and then spread to the table skirt and blankets, then to the curtain on the right, when high temperatures were reached. This caused the glass to break, and the fire finally spread to the boxes, the other curtain, the chair and the table.(Figure 26)

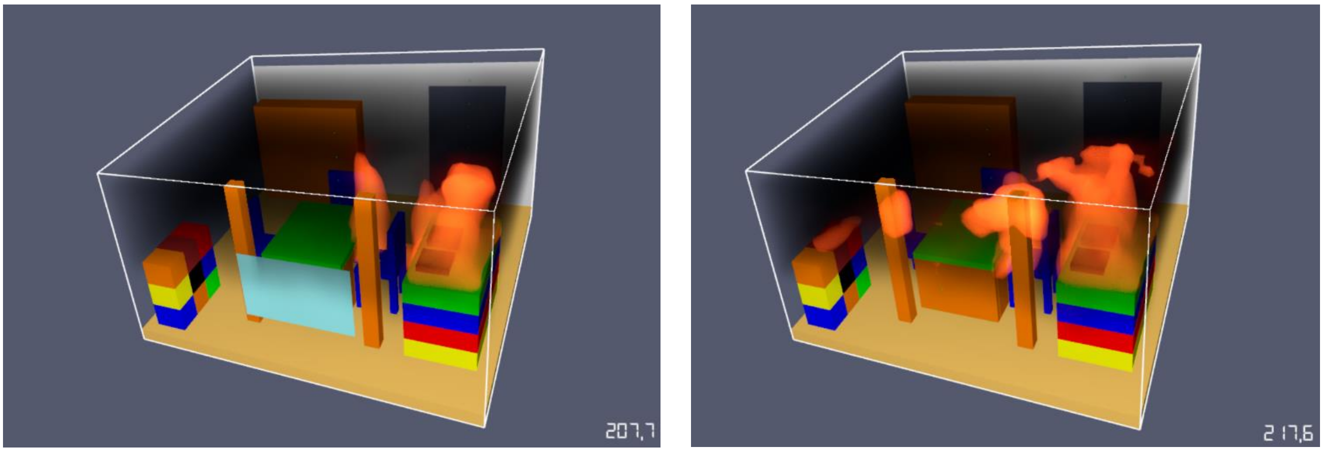

Figure 26. State of the fire before and after the window breakage for room 4

The increase in temperatures can be observed in the planes. (Figure 27)

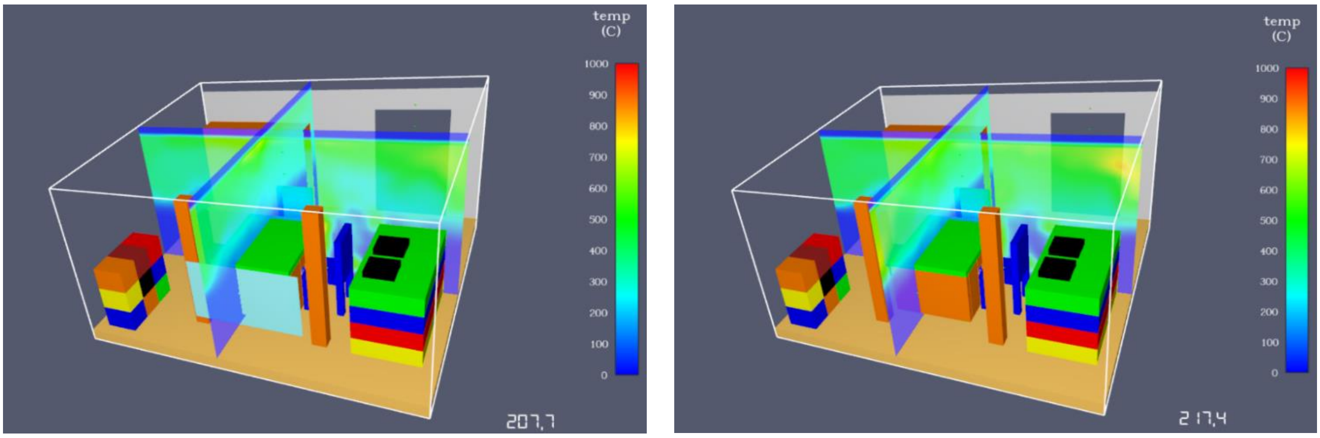

Figure 27. Temperature before and after the window breakage for room 4

State and temperatures of the fire at the end of the simulation.(Figure 28)

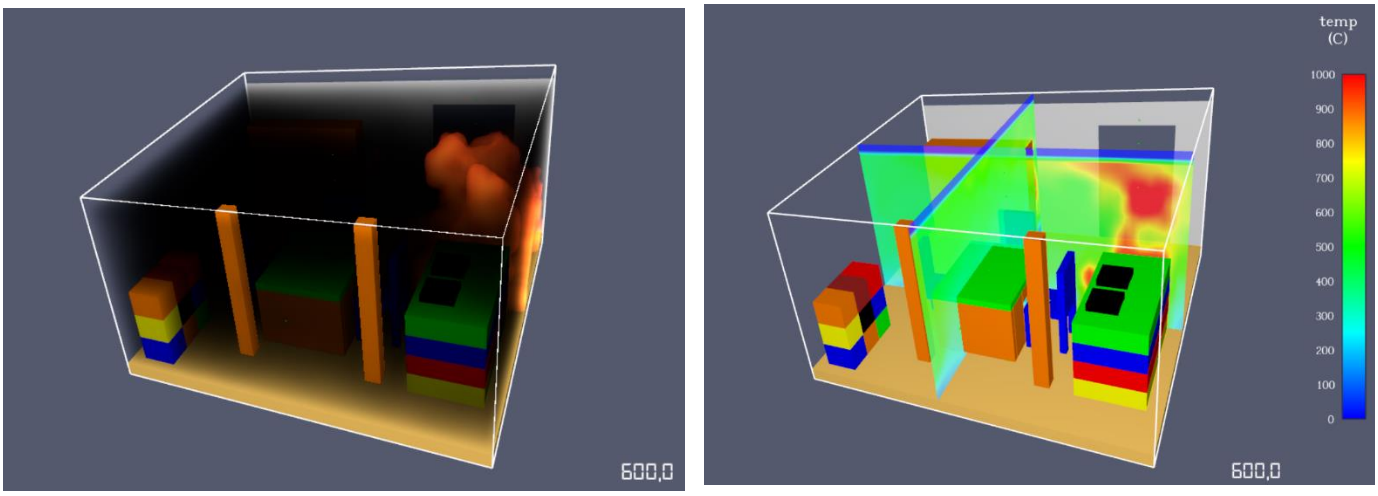

Figure 28. State of the fire at the end of the simulation in room 4

It is clear from the tables that the temperatures increase drastically from second 200 to second 250, when window breaks (second 210).

It can be seen that the final temperatures are very high. This is due to the fact that the fire continues, as can be seen in Figure 28, where it can also be seen that the room is full of smoke.

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	20	20	26	43	51	63
100	21	21	21	29	45	51	72
150	23	23	21	70	106	123	254
200	26	26	34	134	233	266	380
250	50	68	94	373	640	707	767
300	475	376	407	473	477	559	688
350	261	288	268	377	400	457	589
400	226	297	269	386	406	435	623

450	259	287	266	389	417	442	492
500	217	288	278	380	404	479	523
550	228	310	274	380	423	472	760
600	240	292	280	373	395	436	573

Table 10. Temperature in the center of the room 4

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	20	23	26	40	50	60
100	20	20	24	36	51	56	64
150	20	22	27	67	106	135	169
200	21	22	35	123	231	308	352
250	54	112	243	396	397	510	627
300	22	141	275	708	467	539	591
350	84	334	638	722	502	541	517
400	23	75	581	848	554	618	637
450	42	641	768	658	685	736	672
500	28	31	121	737	654	633	656
550	22	174	589	724	773	633	639
600	58	478	784	803	762	807	709

Table 11. Temperature at the door in room 4

Scenario 5:

In the latter room, the fire originated in a blanket due to a badly extinguished cigarette butt.

The image below shows the beginning of the fire.(Figure 30)

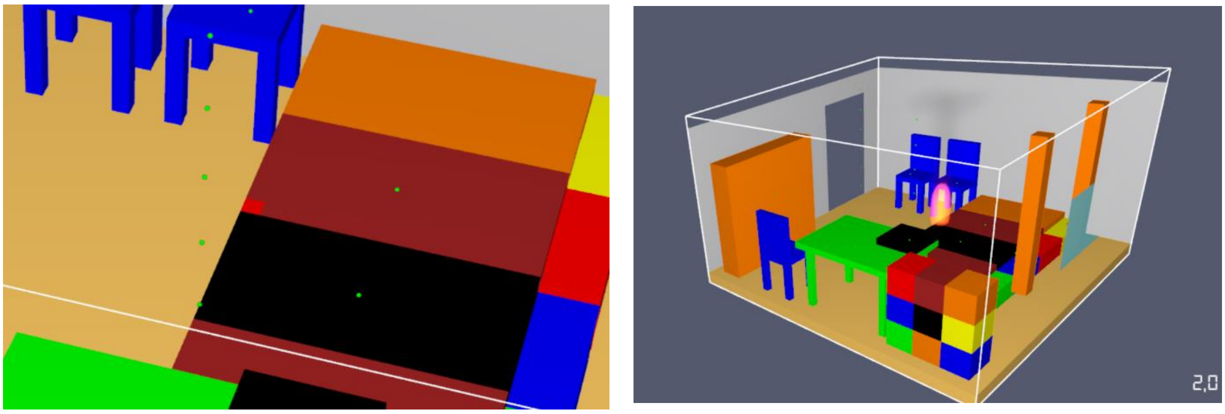

Figure 29. Start of fire for scenario 5

The fire starts in a blanket and quickly spreads to the rest of the blankets and the mattresses underneath them. In the second 190 the window is broken, and immediately after the breakage the fire spreads to the curtains, and then to the boxes and the rest of the furniture.(Figure 31)

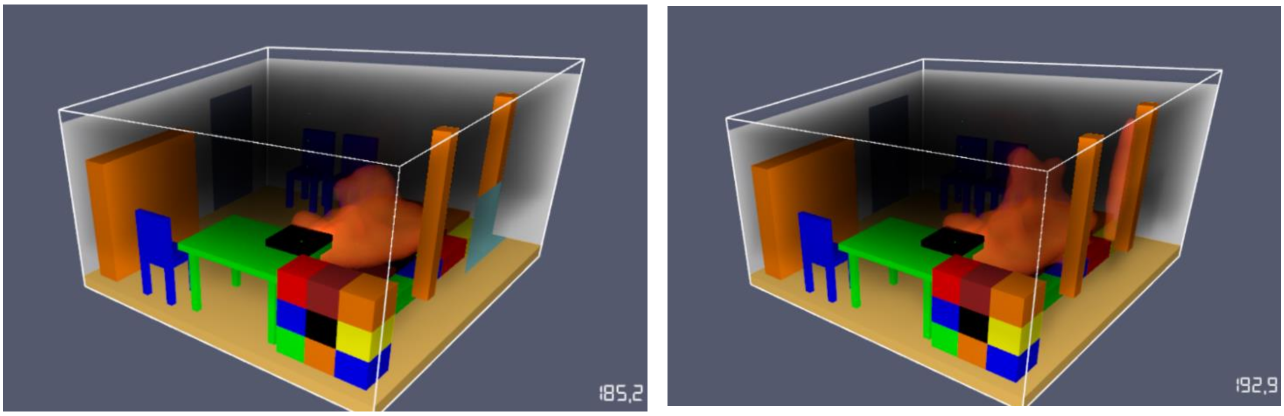

Figure 30. State of the fire before and after the window breakage for room 5

This sharp increase in temperatures can be seen in the planes of Figure 32.

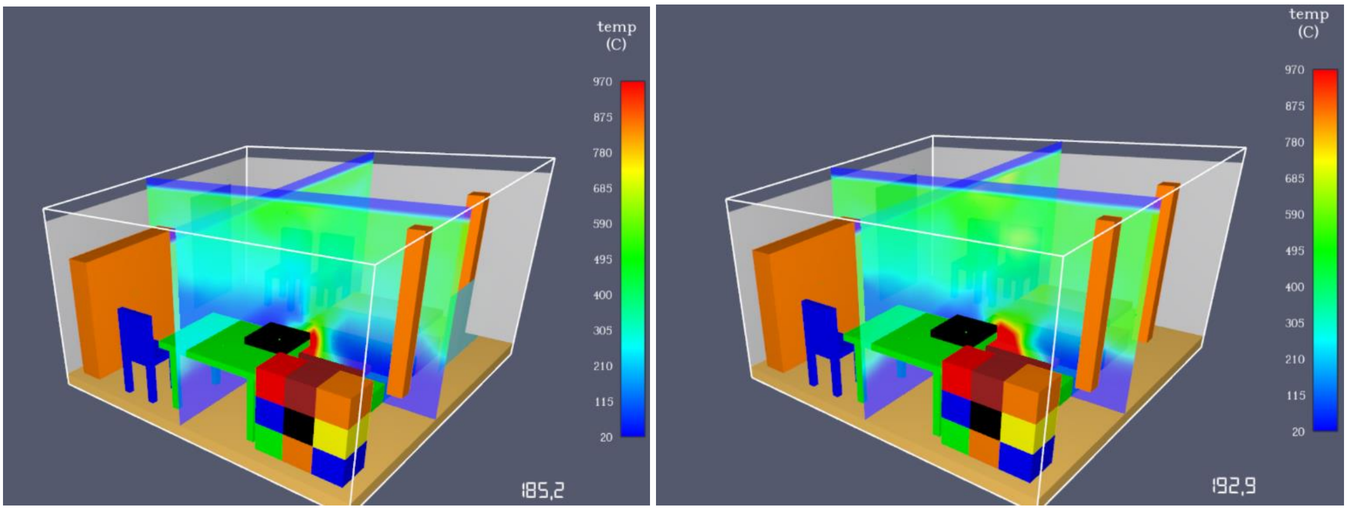

Figure 31. Temperature before and after the window breakage for room 5

It is worth noting the state of the fire and the temperatures at the end of the simulation. The room is full of smoke and the temperatures are very high. This is because most of the furniture is still burning. This can be seen in the tables, since the temperatures are still very high in the second 600, especially at the door. The wardrobe is the last thing that starts to burn and the fire would continue to spread to the rest of the house.(Figure 33)

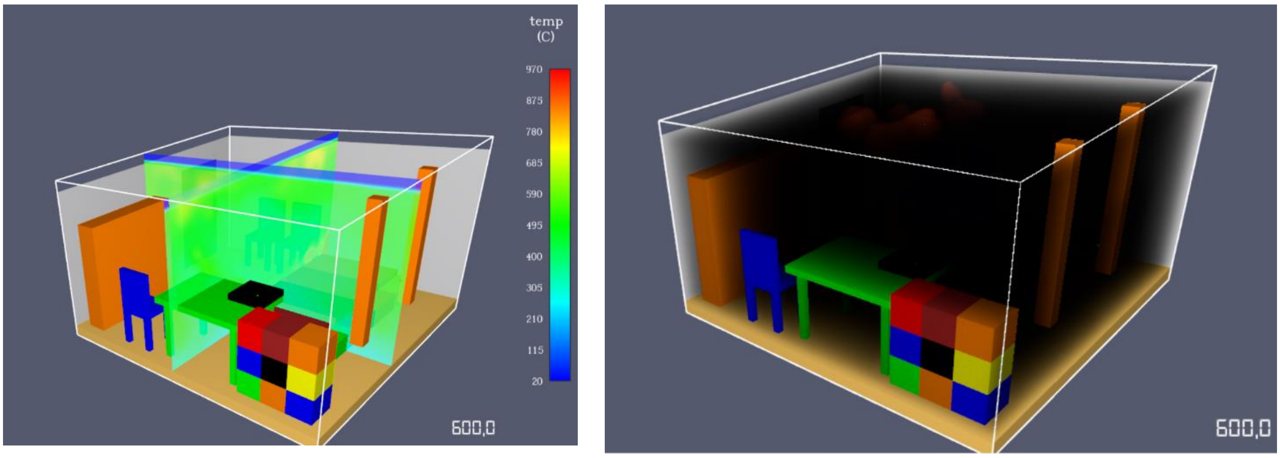

Figure 32. State of the fire at the end of the simulation in room 5

The tables(Table 12 and Table 13) show very clearly the increase in temperatures due to glass breakage, which occurs in the second 190. This increase is greater in the temperatures in the centre of the room because this is where most of the elements are burning.

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	22	22	29	51	63	93
100	20	41	31	42	71	98	130
150	20	188	45	95	153	182	219
200	20	170	220	345	403	506	612
250	20	595	777	947	876	732	642
300	20	409	376	405	414	445	555
350	20	419	409	410	408	433	639
400	20	418	382	400	408	480	660
450	20	387	393	396	428	423	524
500	20	386	392	399	417	456	508
550	20	405	445	479	407	419	550
600	20	429	381	385	409	425	536

Table 12. Temperature in the center of the room 5

Time	0 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
0	20	20	20	20	20	20	20
50	20	20	21	24	51	61	87
100	20	21	25	58	98	110	140
150	23	50	53	127	161	177	215
200	30	79	183	304	350	370	416
250	46	218	459	506	541	569	572

300	25	39	236	757	775	638	645
350	27	526	797	734	701	722	713
400	27	105	415	726	683	833	776
450	25	436	916	920	808	716	669
500	50	149	348	970	920	765	727
550	23	113	628	801	777	771	701
600	22	84	189	929	981	1023	749

Table 13. Temperature at the door in room 5

6. Conclusions

As has been observed in the previous section, all scenarios in which the energy poverty factor is present, whether due to the presence of an excessive number of blankets or the use of electrical appliances with a higher risk, the temperatures are much higher and the fire spreads at a higher speed.

All this has very negative consequences, since the higher the temperature and spread, the less time it takes for the emergency services to arrive and the greater risk to human life.

It is known that it is not possible to achieve a zero probability of fire, but with a little more awareness in these families, it would be possible to reduce this probability and thus to avoid fires caused by ignorance of the danger.

For example, scenarios 3, 4 and 5 are the ones that have the easiest solution. In scenario 3 the fire was caused by carelessness in which the skirt of the table came into contact with the cooker, causing the fire.

In scenario 4 the fire was caused by using a container of alcohol to heat the room and placing it inappropriately close to the mattresses.

In scenario 5, the fire was caused by a badly extinguished cigarette butt on the floor in a room with different blankets.

All these scenarios could easily be avoided by providing information about risks and growing awareness of the dangers on a daily basis. For example, by teaching them to turn off the cooker whenever they are going to be away from the room for a prolonged period of time, by teaching them the dangers of lighting alcohol inside a bedroom and even more so by leaving it to their own children to refill the alcohol while it is still lit. And finally, teaching to throw cigarette butts into ashtrays instead of throwing them on the floor.

Therefore, although promoting quality education for these families is necessary, it cannot be the only solution. Government support is needed to fight against these situations of energy poverty in which families are not able to pay for heating.

Other measures could be providing donations to NGOs to purchase and install smoke detectors in these vulnerable households, as well as providing families with safer appliances such as radiators instead of cookers, or installing glass-ceramic hobs which are safer than butane stoves.

On the other hand, in scenario two the fire was caused by the poor state of the electrical installation. Landlords are responsible of ensuring that installations comply with safety regulations. For this reason, the government should become aware and should impose harsher sanctions and prosecute landlords who take advantage of the situations of these families.

To this must be added the fact that energy poverty is on the rise in our country, especially since the pandemic and the energy crisis that took place, which has been accentuated by the war between Russia and Ukraine, which has led to the most expensive average price in the history of Spain, 544.98 €/MWh. [19]

In 2021, around 6.7 million people in Spain did not have thermal comfort in their homes, which represents 14% of the total Spanish population, and also represents an increase of 31% compared to 2020. This is the aspect that has worsened the most in recent years in our country, and this has its causes in the increase in the price of electricity and the increase in the average price of living due to inflation. As a result, the majority of families suffering from energy poverty are increasingly turning to these more dangerous sources as they are more economical and allow them to have adequate temperatures in their homes. [20]

For all these reasons there is a great need for awareness raising and investment in education in fire safety, especially for this sector of the population. There is also the need to develop new policies to seek to reduce energy poverty within our country.

Tackling this problem would therefore achieve a number of social benefits, such as improving access to electricity for these families.

There is currently no official register of incidents that are caused by fuel poverty, although it is known that in Madrid 6 out of 8 deaths caused by fires occurred in households living in fuel poverty[21]. Furthermore, firefighters are warning that the majority of fires are caused by fuel poverty, highlighting that there is no official data to show that these fires are caused by fuel poverty[22]. So the government should start registering fires in households in energy poverty and study further whether this is indeed the cause of the fire.

Furthermore, in terms of measures implemented against energy poverty Greece was the only country to take energy poverty into account in its national Energy and Climate plan. It is worth noting that the countries with the lowest energy poverty are the Nordics, which shows that energy poverty is more related to socio-economic factors than climate factors, as the countries with the highest energy poverty are Eastern and Southern European countries. One of the main factors leading to lower energy poverty in the Nordic countries is the fact that they have strict building regulations, which is not the case in Spain. This leads to homes being in poorer condition and lacking the necessary heat insulation for adequate thermal comfort.[23]

Most importantly of all, policies and measures to combat this problem would protect one of the most vulnerable sectors of the population, promote a sustainable future and, above all, save lives, which is what really matters.

7. Future Works

In future work, collaboration could take place with an NGO to visit some homes of families suffering from energy poverty. Interviews and surveys could be carried out to gather information and understand which habits are most at risk in order to prepare appropriate training to make these families aware of the dangers they are subjected to on a daily basis. Their homes could also be visited and modelled in FDS by changing the points where the fire originates in order to know the most vulnerable rooms and focus the measures on these rooms or appliances.

Research could be carried out in future work to study the effect of energy poverty measures. A set of households that have received education programmes or have been provided with smoke detectors or safer cookstoves could be compared with those households that have not received any of these supports. The impact of these measures could then be studied to evaluate whether they are actually useful for more policy support.

Also, the viability of grants to incorporate solar panels in households could be studied to see whether the energy produced by the panels could help families get easy access to electricity and reduce their electricity bills, which would allow them to spend more in winter on heating, reducing the number of fires caused by cookers or candles.

Other types of aid could be studied for families suffering from energy poverty. For example, energy audits could be carried out for those families who receive the "Bono Social", and as part of this audit, the risk of fire could be studied to see if, due to the Bono, this risk is reduced.

8. Annex

8.1. Economical study

For this work, the human resources used by both the mentee and the mentors will be taken into account.

The allocated costs will be 40 €/h for the mentors and 10 €/h for the student.

	N^er^ of hours	Unit price (€/h)	TOTAL
Mentors	60	40	2400
Students	320	10	3200
			5600

Table 14. Cost of human resources

The cost of the material resources used should also be included, such as the cost of the office licence, the depreciation of the computer and the cost of the tuition credits. Electricity costs are omitted due to the complexity of calculating them and the small influence they would have on the final cost. It should be noted that the use of the FDS and Smokeview software is free of charge, so there are no licensing fees.

	Price (€)
TFM Enrolment	2.400
Office License	149
Computer depreciation	400
Total	2949

Table 15. Cost of material resources

Therefore the total cost of the work without tax would be the sum of both costs, which would be 8549 €, so adding VAT would give us a total cost of 10344.29 €.

8.2. List of materials used with their properties

The following materials are used in the working models:

- Wood⟶ Used for the table, chairs and bed base.
- Plywood⟶ Used for wardrobe, chest of drawers and bedside table
- Cotton⟶ Used for clothes inside boxes
- Polyester⟶ Used for curtain, blankets and table skirt
- Polyurethane/foam⟶ Used for mattresses

The properties for the materials used have been obtained from SFPE Handbook of Fire Protection Engineering [24].

	Specific Heat(kJ/kg·°C)	**Conductivity(W/m·k)**	**Density(kg/m^3)**	**Ignition Temperature(°C)**
Wood	2.5	0.15	600	350
Plywood	1.66	0.15	400	300
Cotton	0.72	0.065	448	160
Polyester	1.9	0.08	1200	180
Polyurethane/foam	1.8	0.028	60	250

Table 16. Properties for the materials used

8.3. HRRPUA curves of furniture

For the curves, the results of previous studies for the behaviour of furniture with similar dimensions to those used in the rooms will be used. The maximum HRR as well as the growth ramp and its factors have to be taken into account.

For the table[25]:

Table	**HRR**	**Time (s)**	**0**	**5**	**10**	**20**	**30**
	200	Factor	0	0.5	0.7	0.9	1

Table 17. HRR for the table

For the chair[26]:

Chair	**HRR**	**Time (s)**	**0**	**10**	**20**	**35**	**60**
	190	Factor	0	0.3	0.5	0.9	1

Table 18. HRR for the chair

For wardrobe, chest of drawers and bedside table[27]:

Only one study has been found for a wardrobe, but as the rest of the furniture is made of the same material, the same characteristics will be assumed.

Wardrobe	**HRR**	**Time (s)**	**0**	**30**	**60**	**90**
	270	Factor	0	0.5	0.7	1

Table 19. HRR for the wardrobe

For the Mattress.[28]

Mattress	**HRR**	**Time (s)**	**0**	**1**	**10**	**30**	**45**
	300	Factor	0	0.2	0.4	0.8	1

Table 20. HRR for the matress

For the blanket[29]:

Blanket	**HRR**	**Time (s)**	**0**	**1**	**5**	**20**
	180	Factor	0	0.2	0.6	1

Table 21. HRR for the blanket

For the curtain[26]:

Curtain	**HRR**	**Time (s)**	**0**	**1**	**10**	**20**
	150	Factor	0	0.7	0.95	1

Table 22. HRR for the curtain

For the box of clothes[30]:

Box	**HRR**	**Time (s)**	**0**	**1**	**5**	**30**
	280	Factor	0	0.3	0.55	1

Table 23. HRR of the box

8.4. Combustion heats and weights of furniture

The heats of combustion for the materials used have been obtained from SFPE Handbook of Fire Protection Engineering [24].

Material	MJ/kg
Wood	21.7
Plywood	18.8
Cotton	19.4
Polyester	20.3
Polyurethane/foam	24

Table 24. Heat of combustion of the materials

While the approximate weights have been obtained from the Ikea website.[31]

Element	Weight (kg)
Table	20
Chair	6
Wardrobe	40
Chest of drawers	30
Bedside table	10
Mattress	20
Blanket	2
Curtain	2
Box	10

Table 25. Weight of the furniture

8.5. Calculations to obtain burning time

The weight of each piece of furniture is multiplied by the heat of combustion of the Table 24.

This will give the MJ produced during the combustion of each piece of furniture, and if we divide it by the Heat Release Rate (kW) we will obtain the seconds it will take for each piece of furniture to be consumed.

	Weight (kg)	Energy (MJ)	HRR (Kw)	Time (s)
Table	20	434	200	2170
Chair	6	130.2	190	685.26
Wardrobe	40	752	270	2785.18
Chest of drawers	30	564	270	2088.89
Bedside table	10	188	270	696.29
Mattress	20	480	300	1600
Blanket	2	38.8	180	215.55
Curtain	4	81.2	150	541.33
Box	10	194	280	718.52

Table 26. Calculations to obtain the ignition time

As can be seen from the table, the only element that is consumed in the seconds that the fire lasts is the blanket, which takes 215 seconds from the moment it starts to burn.

Therefore, it is necessary to describe the curve where the HRR decreases as the blanket is consumed. [29]

Blanket	**HRR**	**Time (s)**	**155**	**175**	**190**	**215**
	180	Factor	1	0.8	0.5	0

Table 27. HRR of the blanket when it is consuming

8.6. FDS Code

Common code for all scenarios

```
&TIME T_END=600.0/

&MESH ID='Room', IJK=50,50,30, XB=0.0,5.0,0.0,5.0,0.0,3.0/

&MATL ID='FOAM',

      SPECIFIC_HEAT=1.8,

      CONDUCTIVITY=0.025,

      DENSITY=60.0/

&MATL ID='WOOD',

      SPECIFIC_HEAT=2.5,

      CONDUCTIVITY=0.15,

      DENSITY=600.0/

&MATL ID='PLYWOOD',

      SPECIFIC_HEAT=1.66,

      CONDUCTIVITY=0.15,

      DENSITY=400.0/

&MATL ID='COTTON',

      SPECIFIC_HEAT=0.72,

      CONDUCTIVITY=0.065,

      DENSITY=448.0/

&MATL ID='POLYESTER',

      SPECIFIC_HEAT=1.9,

      CONDUCTIVITY=0.08,

      DENSITY=1200.0/

&SURF ID='Fire',

      COLOR='RED',

      HRRPUA=5000.0,

      RAMP_Q='T_SQ'

&RAMP ID='T_SQ', T=0, F=0/

&RAMP ID='T_SQ', T=1, F=1/

&RAMP ID='T_SQ', T=10, F=1/

&RAMP ID='T_SQ', T=60, F=1/

&SURF ID='Table',

      COLOR='RED',

      HRRPUA=200.0,

       MATL_ID='WOOD',
```

```
      THICKNESS=0.1,
      IGNITION_TEMPERATURE=350,
      RAMP_Q='T2_SQ'/
&RAMP ID='T2_SQ', T=0,      F=0/
&RAMP ID='T2_SQ', T=5,      F=0.5/
&RAMP ID='T2_SQ', T=10,     F=0.7/
&RAMP ID='T2_SQ', T=20,     F=0.9/
&RAMP ID='T2_SQ', T=30,     F=1/
&RAMP ID='T2_SQ', T=600,    F=1/
&SURF ID='Chair',
      COLOR='RED',
      HRRPUA=190.0,
       MATL_ID='WOOD',
      THICKNESS=0.1,
      IGNITION_TEMPERATURE=350,
      RAMP_Q='T3_SQ'/
&RAMP ID='T3_SQ', T=0,      F=0/
&RAMP ID='T3_SQ', T=10,     F=0.3/
&RAMP ID='T3_SQ', T=20,     F=0.5/
&RAMP ID='T3_SQ', T=35,     F=0.9/
&RAMP ID='T3_SQ', T=60,     F=1/
&RAMP ID='T3_SQ', T=600,    F=1/
&SURF ID='Curtain',
      COLOR='RED',
      HRRPUA=150.0,
       MATL_ID='POLYESTER',
      THICKNESS=0.1,
      IGNITION_TEMPERATURE=180,
      RAMP_Q='T4_SQ'/
&RAMP ID='T4_SQ', T=0,      F=0/
&RAMP ID='T4_SQ', T=1,      F=0.7/
&RAMP ID='T4_SQ', T=10,     F=0.95/
&RAMP ID='T4_SQ', T=20,     F=1/
&RAMP ID='T4_SQ', T=600,    F=1/
&SURF ID='Wardrobe',
      COLOR='RED',
```

```
      HRRPUA=270.0,
       MATL_ID='PLYWOOD',
      THICKNESS=0.1,
      IGNITION_TEMPERATURE=300,
      RAMP_Q='T6_SQ'/
&RAMP ID='T6_SQ', T=0,       F=0/
&RAMP ID='T6_SQ', T=30,      F=0.5/
&RAMP ID='T6_SQ', T=60,      F=0.7/
&RAMP ID='T6_SQ', T=90,      F=1/
&RAMP ID='T6_SQ', T=600,     F=1/
&SURF ID='Box',
      COLOR='RED',
      HRRPUA=280.0,
       MATL_ID='COTTON',
      THICKNESS=0.1,
      IGNITION_TEMPERATURE=160,
      RAMP_Q='T7_SQ'/
&RAMP ID='T7_SQ', T=0,       F=0/
&RAMP ID='T7_SQ', T=1,       F=0.3/
&RAMP ID='T7_SQ', T=5,       F=0.55/
&RAMP ID='T7_SQ', T=30,      F=1/
&RAMP ID='T7_SQ', T=600,     F=1/
&SURF ID='Blanket',
      COLOR='RED',
      HRRPUA=180.0,
       MATL_ID='COTTON',
      THICKNESS=0.1,
      IGNITION_TEMPERATURE=160,
      RAMP_Q='T8_SQ'/
&RAMP ID='T8_SQ', T=0,       F=0/
&RAMP ID='T8_SQ', T=1,       F=0.2/
&RAMP ID='T8_SQ', T=5,       F=0.6/
&RAMP ID='T8_SQ', T=20,      F=1/
&RAMP ID='T8_SQ', T=155,     F=1/
&RAMP ID='T8_SQ', T=175,     F=0.8/
&RAMP ID='T8_SQ', T=195,     F=0.5/
```

```
&RAMP ID='T8_SQ', T=215, F=0/

&SURF ID='Mattress',

      COLOR='RED',

      HRRPUA=300.0,

       MATL_ID='FOAM',

      THICKNESS=0.1,

      IGNITION_TEMPERATURE=250,

      RAMP_Q='T9_SQ'/

&RAMP ID='T9_SQ', T=0,      F=0/

&RAMP ID='T9_SQ', T=1,      F=0.2/

&RAMP ID='T9_SQ', T=10,     F=0.4/

&RAMP ID='T9_SQ', T=30,     F=0.8/

&RAMP ID='T9_SQ', T=45,     F=1/

&RAMP ID='T9_SQ', T=600,    F=1/

&OBST      ID='Obstruction',      XB=0.0,5.0,0.0,0.0,0.0,2.8,      RGB=204,204,204,
TRANSPARENCY=0.74902/

&OBST      ID='Obstruction',      XB=0.0,5.0,5.0,5.0,0.0,2.8,      RGB=204,204,204,
TRANSPARENCY=0.74902/

&OBST      ID='Obstruction',      XB=0.0,0.0,0.0,5.0,0.0,2.8,      RGB=204,204,204,
TRANSPARENCY=0.74902/

&OBST      ID='Obstruction',      XB=5.0,5.0,0.0,5.0,2.0,2.8,      RGB=204,204,204,
TRANSPARENCY=0.74902/

&OBST      ID='Obstruction',      XB=5.0,5.0,0.0,5.0,0.0,1.0,      RGB=204,204,204,
TRANSPARENCY=0.74902/

&OBST      ID='Obstruction',      XB=5.0,5.0,0.0,2.0,1.0,2.0,      RGB=204,204,204,
TRANSPARENCY=0.74902/

&OBST      ID='Obstruction',      XB=5.0,5.0,3.5,5.0,1.0,2.0,      RGB=204,204,204,
TRANSPARENCY=0.74902/

&OBST ID='Floor', XB=0.0,5.0,0.0,5.0,0.0,0.2/

&OBST ID='Ceiling', XB=0.0,5.0,0.0,5.0,2.8,3.0, COLOR='INVISIBLE'/

&HOLE ID='Puerta', XB=-5.0E-3,0.75,3.3,4.5,0.2,2.4, RGB=240,240,240, TRANSPARENCY=0.0/

&HOLE ID='Ventana', XB=4.3,5.005,2.0,3.5,1,2,DEVC_ID='control temperature'/

&OBST XB= 5, 5, 2.0, 3.5, 1, 2, RGB=160, 252, 255, TRANSPARENCY=0.85, DEVC_ID='control
temperature1'/

&DEVC  ID='control  temperature',  QUANTITY  =  'TEMPERATURE',  XYZ  =  4.8,  2.6,  1.4,
SETPOINT=220, INITIAL_STATE=.FALSE. /

&VENT ID='Mesh Vent: Room [XMIN]', SURF_ID='OPEN', XB=0.0,0.0,0.0,5.0,0.0,3.0/

&VENT ID='Mesh Vent: Room [YMAX]', SURF_ID='OPEN', XB=0.0,5.0,5.0,5.0,0.0,3.0/

&VENT ID='Mesh Vent: Room [ZMAX]', SURF_ID='OPEN', XB=0.0,5.0,0.0,5.0,3.0,3.0/

&VENT ID='Mesh Vent: Room [ZMIN]', SURF_ID='OPEN', XB=0.0,5.0,0.0,5.0,0.0,0.0/
```

```
/ Room centre temperature
&DEVC XYZ=2.5,2.5,0.2, QUANTITY='TEMPERATURE', ID='MTEMPE1'/
&DEVC XYZ=2.5,2.5,0.6, QUANTITY='TEMPERATURE', ID='MTEMPE2'/
&DEVC XYZ=2.5,2.5,1.0, QUANTITY='TEMPERATURE', ID='MTEMPE3'/
&DEVC XYZ=2.5,2.5,1.4, QUANTITY='TEMPERATURE', ID='MTEMPE4'/
&DEVC XYZ=2.5,2.5,1.8, QUANTITY='TEMPERATURE', ID='MTEMPE5'/
&DEVC XYZ=2.5,2.5,2.2, QUANTITY='TEMPERATURE', ID='MTEMPE6'/
&DEVC XYZ=2.5,2.5,2.6, QUANTITY='TEMPERATURE', ID='MTEMPE7'/
/ Door Temperature
&DEVC XYZ=0.3,4.0,0.2, QUANTITY='TEMPERATURE', ID='PTEMPE1'/
&DEVC XYZ=0.3,4.0,0.6, QUANTITY='TEMPERATURE', ID='PTEMPE2'/
&DEVC XYZ=0.3,4.0,1.0, QUANTITY='TEMPERATURE', ID='PTEMPE3'/
&DEVC XYZ=0.3,4.0,1.4, QUANTITY='TEMPERATURE', ID='PTEMPE4'/
&DEVC XYZ=0.3,4.0,1.8, QUANTITY='TEMPERATURE', ID='PTEMPE5'/
&DEVC XYZ=0.3,4.0,2.2, QUANTITY='TEMPERATURE', ID='PTEMPE6'/
&DEVC XYZ=0.3,4.0,2.6, QUANTITY='TEMPERATURE', ID='PTEMPE7'/
&SLCF QUANTITY='TEMPERATURE', ID='X', PBX=2.5/
&SLCF QUANTITY='TEMPERATURE', ID='Y', PBY=2.2/
```

Code scenario 1

```
/Table
&OBST ID='Table', XB=2.6,4.4,0.2,1.2,1.2,1.4, COLOR='GREEN', SURF_ID='Table'/
&OBST ID='TL1',   XB=2.9,3.0,0.3,0.4,0.2,1.2, COLOR='GREEN', SURF_ID='Table'/
&OBST ID='TL2',   XB=2.9,3.0,1.0,1.1,0.2,1.2, COLOR='GREEN', SURF_ID='Table'/
&OBST ID='TL3',   XB=4.1,4.2,0.3,0.4,0.2,1.2, COLOR='GREEN', SURF_ID='Table'/
&OBST ID='TL4',   XB=4.1,4.2,1.0,1.1,0.2,1.2, COLOR='GREEN', SURF_ID='Table'/
/Bed
&OBST ID='Mattress',  XB=2.5,4.3,3.9,4.8,0.8,1.1, COLOR='YELLOW', SURF_ID='Mattress'/
&OBST ID='BoxSpring', XB=2.5,4.3,3.9,4.8,0.7,0.8, COLOR='BLACK',  SURF_ID='Table'/
&OBST ID='PC1',       XB=2.6,2.7,4.0,4.1,0.2,0.7, COLOR='BLACK',  SURF_ID='Table'/
&OBST ID='PC2',       XB=2.6,2.7,4.6,4.7,0.2,0.7, COLOR='BLACK',  SURF_ID='Table'/
&OBST ID='PC3',       XB=4.1,4.2,4.0,4.1,0.2,0.7, COLOR='BLACK',  SURF_ID='Table'/
&OBST ID='PC4',       XB=4.1,4.2,4.6,4.7,0.2,0.7, COLOR='BLACK',  SURF_ID='Table'/
&OBST ID='BedsideT',  XB=3.9,4.3,3.3,3.7,0.2,1.0, COLOR='BROWN',  SURF_ID='Table'/
&OBST ID='Wardrobe',  XB=0.2,0.6,0.2,2.2,0.2,2.2, COLOR='ORANGE', SURF_ID='Wardrobe'/
/Curtains
&OBST ID='Curtain1', XB=4.5,4.7,1.9,2.1,0.6,2.8, COLOR='ORANGE', SURF_ID='Curtain'/
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```
&OBST ID='Curtain2', XB=4.5,4.7,3.6,3.8,0.6,2.8, COLOR='ORANGE', SURF_ID='Curtain'/

/Chair

&OBST ID='Seat',     XB=3.1,3.7,1.2,1.7,0.8,0.9, COLOR='BLUE', SURF_ID='Chair'/

&OBST ID='Backrest', XB=3.1,3.7,1.6,1.7,0.8,1.7, COLOR='BLUE', SURF_ID='Chair'/

&OBST ID='CL1',      XB=3.1,3.2,1.2,1.3,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/

&OBST ID='CL2',      XB=3.1,3.2,1.6,1.7,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/

&OBST ID='CL3',      XB=3.6,3.7,1.2,1.3,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/

&OBST ID='CL4',      XB=3.6,3.7,1.6,1.7,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/

/ Chest of drawers

&OBST                                                            ID='ChestOfDrawers',
XB=1.0,2.0,0.2,0.8,0.2,1.4,COLOR='BROWN',SURF_ID='Wardrobe'/


&OBST ID='Cable', XB=4.6,4.7,1.9,2.0,0.2,0.3,COLOR='ORANGE'/

&VENT ID='Vent1', SURF_ID='Fire', XB=4.6,4.7,1.9,2.0,0.3,0.3, COLOR='RED'/
```

Code scenario 2

```
/Table

&OBST ID='Table', XB=2.4,4.0,1.8,3.0,1.2,1.3, COLOR='GREEN', SURF_ID='Table'/

&OBST ID='TL1',   XB=2.5,2.6,1.9,2.0,0.2,1.2, COLOR='GREEN', SURF_ID='Table'/

&OBST ID='TL2',   XB=2.5,2.6,2.8,2.9,0.2,1.2, COLOR='GREEN', SURF_ID='Table'/

&OBST ID='TL3',   XB=3.8,3.9,1.9,2.0,0.2,1.2, COLOR='GREEN', SURF_ID='Table'/

&OBST ID='TL4',   XB=3.8,3.9,2.8,2.9,0.2,1.2, COLOR='GREEN', SURF_ID='Table'/

/Mattress

&OBST ID='Mattress1', XB=2.5,4.3,3.9,4.8,0.2,0.5, COLOR='YELLOW', SURF_ID='Mattress'/

&OBST ID='Mattress2', XB=2.5,4.3,3.9,4.8,0.5,0.8, COLOR='RED',    SURF_ID='Mattress'/

&OBST ID='Mattress3', XB=2.5,4.3,3.9,4.8,0.8,1.1, COLOR='BLUE',   SURF_ID='Mattress'/

&OBST ID='Mattress4', XB=2.5,4.3,3.9,4.8,1.1,1.4, COLOR='GREEN',  SURF_ID='Mattress'/

&OBST ID='Wardrobe',  XB=0.2,0.6,0.2,2.2,0.2,2.2, COLOR='ORANGE', SURF_ID='Wardrobe'/

/Boxes

&OBST ID='Box1', XB=3.6,4.0,0.2,0.7,0.2,0.6, COLOR='GREEN', SURF_ID='Box'/

&OBST ID='Box1', XB=3.6,4.0,0.2,0.7,0.6,1.0, COLOR='BLUE',  SURF_ID='Box'/

&OBST ID='Box3', XB=3.6,4.0,0.2,0.7,1.0,1.4, COLOR='RED',   SURF_ID='Box'/

&OBST ID='Box4', XB=4.0,4.4,0.2,0.7,0.2,0.6, COLOR='ORANGE',SURF_ID='Box'/

&OBST ID='Box5', XB=4.0,4.4,0.2,0.7,0.6,1.0, COLOR='BLACK', SURF_ID='Box'/

&OBST ID='Box6', XB=4.0,4.4,0.2,0.7,1.0,1.4, COLOR='BROWN', SURF_ID='Box'/

&OBST ID='Box7', XB=4.4,4.8,0.2,0.7,0.2,0.6, COLOR='BLUE',  SURF_ID='Box'/

&OBST ID='Box8', XB=4.4,4.8,0.2,0.7,0.6,1.0, COLOR='YELLOW',SURF_ID='Box'/
```

```
&OBST ID='Box9',     XB=4.4,4.8,0.2,0.7,1.0,1.4, COLOR='ORANGE', SURF_ID='Box'/
&OBST ID='Curtain1', XB=4.5,4.7,1.8,2.0,0.6,2.8, COLOR='ORANGE', SURF_ID='Curtain'/
&OBST ID='Curtain2', XB=4.5,4.7,3.5,3.7,0.6,2.8, COLOR='ORANGE', SURF_ID='Curtain'/
&OBST ID='Blanket1', XB=3.5,3.9,2.2,2.6,1.3,1.4, COLOR='ORANGE', SURF_ID='Blanket'/
&OBST ID='Blanket2', XB=2.6,3.0,2.3,2.7,1.3,1.4, COLOR='ORANGE', SURF_ID='Blanket'/
/CHAIR1
&OBST ID='1Seat',     XB=1.8,2.4,2.1,2.7,0.8,0.9, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='1Backrest', XB=1.8,1.9,2.1,2.7,0.8,1.6, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='1CL1',      XB=1.8,1.9,2.1,2.2,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='1CL2',      XB=1.8,1.9,2.6,2.7,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='1CL3',      XB=2.3,2.4,2.1,2.2,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='1CL4',      XB=2.3,2.4,2.6,2.7,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
/CHAIR2
&OBST ID='2Seat',     XB=2.9,3.5,3.0,3.6,0.8,0.9, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='2Backrest', XB=2.9,3.5,3.5,3.6,0.8,1.6, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='2CL1',      XB=2.9,3.0,3.0,3.1,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='2CL2',      XB=2.9,3.0,3.5,3.6,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='2CL3',      XB=3.4,3.5,3.0,3.1,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='2CL4',      XB=3.4,3.5,3.5,3.6,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
/CHAIR3
&OBST ID='3Seat',     XB=2.9,3.5,1.2,1.8,0.8,0.9, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='3Backrest', XB=2.9,3.5,1.2,1.3,0.8,1.6, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='3CL1',      XB=2.9,3.0,1.2,1.3,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='3CL2',      XB=2.9,3.0,1.7,1.8,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='3CL3',      XB=3.4,3.5,1.2,1.3,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
&OBST ID='3CL4',      XB=3.4,3.5,1.7,1.8,0.2,0.8, COLOR='BLUE', SURF_ID='Chair'/
/CHAIR4
&OBST ID='4Seat',     XB=3.6,4.2,2.1,2.7,0.8,0.9,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='4Backrest', XB=4.1,4.2,2.1,2.7,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='4CL1',      XB=3.6,3.7,2.1,2.2,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='4CL2',      XB=3.6,3.7,2.6,2.7,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='4CL3',      XB=4.1,4.2,2.1,2.2,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='4CL4',      XB=4.1,4.2,2.6,2.7,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/

&OBST ID='Cable', XB=4.6,4.7,1.9,2.0,0.2,0.3, COLOR='ORANGE'/
&VENT ID='Vent1', XB=4.6,4.7,1.9,2.0,0.3,0.3, COLOR='RED', SURF_ID='Fire'/
```

Code scenario 3

```
/Table
&OBST ID='Table', XB=2.4,4.0,1.8,3.0,1.2,1.3,COLOR='GREEN',SURF_ID='Table'/
&OBST ID='TL1',   XB=2.5,2.6,1.9,2.0,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
&OBST ID='TL2',   XB=2.5,2.6,2.8,2.9,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
&OBST ID='TL3',   XB=3.8,3.9,1.9,2.0,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
&OBST ID='TL4',   XB=3.8,3.9,2.8,2.9,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
/Camas
&OBST ID='Mattress1', XB=2.5,4.3,3.9,4.8,0.2,0.5, COLOR='YELLOW',SURF_ID='Mattress'/
&OBST ID='Mattress2', XB=2.5,4.3,3.9,4.8,0.5,0.8, COLOR='RED',   SURF_ID='Mattress'/
&OBST ID='Mattress3', XB=2.5,4.3,3.9,4.8,0.8,1.1, COLOR='BLUE',  SURF_ID='Mattress'/
&OBST ID='Mattress4', XB=2.5,4.3,3.9,4.8,1.1,1.4, COLOR='GREEN', SURF_ID='Mattress'/
&OBST ID='BlanketA',  XB=3.0,3.4,4.0,4.4,1.4,1.5, COLOR='BLACK', SURF_ID='Blanket'/
&OBST ID='BlanketB',  XB=3.6,4.0,4.0,4.4,1.4,1.5, COLOR='BLACK', SURF_ID='Blanket'/

&OBST ID='Wardrobe', XB=0.2,0.6,0.2,2.2,0.2,2.2,COLOR='ORANGE',SURF_ID='Wardrobe'/
/Boxes
&OBST ID='Box1', XB=3.6,4.0,0.2,0.7,0.2,0.6,COLOR='GREEN', SURF_ID='Box'/
&OBST ID='Box2', XB=3.6,4.0,0.2,0.7,0.6,1.0,COLOR='BLUE',  SURF_ID='Box'/
&OBST ID='Box3', XB=3.6,4.0,0.2,0.7,1.0,1.4,COLOR='RED',   SURF_ID='Box'/
&OBST ID='Box4', XB=4.0,4.4,0.2,0.7,0.2,0.6,COLOR='ORANGE',SURF_ID='Box'/
&OBST ID='Box5', XB=4.0,4.4,0.2,0.7,0.6,1.0,COLOR='BLACK', SURF_ID='Box'/
&OBST ID='Box6', XB=4.0,4.4,0.2,0.7,1.0,1.4,COLOR='BROWN', SURF_ID='Box'/
&OBST ID='Box7', XB=4.4,4.8,0.2,0.7,0.2,0.6,COLOR='BLUE',  SURF_ID='Box'/
&OBST ID='Box8', XB=4.4,4.8,0.2,0.7,0.6,1.0,COLOR='YELLOW',SURF_ID='Box'/
&OBST ID='Box9', XB=4.4,4.8,0.2,0.7,1.0,1.4,COLOR='ORANGE',SURF_ID='Box'/
/Curtains
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/Blankets Table
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&OBST ID='Blanket3', XB=2.9,3.5,1.8,1.9,1.0,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
&OBST ID='Blanket4', XB=2.4,2.9,2.9,3.0,0.3,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
&OBST ID='Blanket5', XB=2.9,3.5,2.9,3.0,1.0,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
&OBST ID='Blanket6', XB=3.5,4.0,2.9,3.0,0.3,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
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&OBST ID='Blanket9',  XB=2.4,2.5,2.7,3.0,0.3,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
&OBST ID='Blanket10', XB=3.9,4.0,1.8,3.0,0.3,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
/CHAIR1
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&OBST ID='1Backrest', XB=1.8,1.9,2.1,2.7,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='1CL1',       XB=1.8,1.9,2.1,2.2,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='1CL2',       XB=1.8,1.9,2.6,2.7,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='1CL3',       XB=2.3,2.4,2.1,2.2,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='1CL4',       XB=2.3,2.4,2.6,2.7,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
/CHAIR2
&OBST ID='2Seat',      XB=2.9,3.5,3.0,3.6,0.8,0.9,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2Backrest', XB=2.9,3.5,3.5,3.6,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL1',       XB=2.9,3.0,3.0,3.1,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL2',       XB=2.9,3.0,3.5,3.6,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL3',       XB=3.4,3.5,3.0,3.1,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL4',       XB=3.4,3.5,3.5,3.6,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
/CHAIR3
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&OBST ID='3Backrest', XB=2.9,3.5,1.2,1.3,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL1',       XB=2.9,3.0,1.2,1.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL2',       XB=2.9,3.0,1.7,1.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL3',       XB=3.4,3.5,1.2,1.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL4',       XB=3.4,3.5,1.7,1.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/

&OBST ID='Radiator', XB=2.9,3.2,2.1,2.4,0.2,0.4, COLOR='ORANGE'/
&VENT ID='Vent1',    XB=3.1,3.2,2.3,2.4,0.4,0.4, COLOR='RED', SURF_ID='Fire', /
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Code scenario 4

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&OBST ID='TL2',   XB=2.5,2.6,2.8,2.9,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
&OBST ID='TL3',   XB=3.8,3.9,1.9,2.0,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
&OBST ID='TL4',   XB=3.8,3.9,2.8,2.9,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
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&OBST ID='Mattress2', XB=2.5,4.3,3.9,4.8,0.5,0.8,COLOR='RED',   SURF_ID='Mattress'/
&OBST ID='Mattress3', XB=2.5,4.3,3.9,4.8,0.8,1.1,COLOR='BLUE',  SURF_ID='Mattress'/
&OBST ID='Mattress4', XB=2.5,4.3,3.9,4.8,1.1,1.4,COLOR='GREEN', SURF_ID='Mattress'/
&OBST ID='BlanketA',  XB=3.0,3.4,4.0,4.4,1.4,1.5,COLOR='BLACK', SURF_ID='Blanket'/
&OBST ID='BlanketB',  XB=3.6,4.0,4.0,4.4,1.4,1.5,COLOR='BLACK', SURF_ID='Blanket'/
&OBST ID='Wardrobe',  XB=0.2,0.6,0.2,2.2,0.2,2.2,COLOR='ORANGE',SURF_ID='Wardrobe'/
/BOXES
&OBST ID='Box1', XB=3.6,4.0,0.2,0.7,0.2,0.6,COLOR='GREEN', SURF_ID='Box'/
&OBST ID='Box2', XB=3.6,4.0,0.2,0.7,0.6,1.0,COLOR='BLUE',  SURF_ID='Box'/
&OBST ID='Box3', XB=3.6,4.0,0.2,0.7,1.0,1.4,COLOR='RED',   SURF_ID='Box'/
&OBST ID='Box4', XB=4.0,4.4,0.2,0.7,0.2,0.6,COLOR='ORANGE',SURF_ID='Box'/
&OBST ID='Box5', XB=4.0,4.4,0.2,0.7,0.6,1.0,COLOR='BLACK', SURF_ID='Box'/
&OBST ID='Box6', XB=4.0,4.4,0.2,0.7,1.0,1.4,COLOR='BROWN', SURF_ID='Box'/
&OBST ID='Box7', XB=4.4,4.8,0.2,0.7,0.2,0.6,COLOR='BLUE',  SURF_ID='Box'/
&OBST ID='Box8', XB=4.4,4.8,0.2,0.7,0.6,1.0,COLOR='YELLOW',SURF_ID='Box'/
&OBST ID='Box9', XB=4.4,4.8,0.2,0.7,1.0,1.4,COLOR='ORANGE',SURF_ID='Box'/
/ Curtains
&OBST ID='Curtain1', XB=4.5,4.7,1.8,2.0,0.6,2.8,COLOR='ORANGE',SURF_ID='Curtain'/
&OBST ID='Curtain2', XB=4.5,4.7,3.5,3.7,0.6,2.8,COLOR='ORANGE',SURF_ID='Curtain'/
/Blankets Table
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&OBST ID='Blanket3',  XB=2.9,3.5,1.8,1.9,1.0,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
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&OBST ID='Blanket6',  XB=3.5,4.0,2.9,3.0,0.3,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
&OBST ID='Blanket7',  XB=2.4,2.5,1.8,2.1,0.3,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
&OBST ID='Blanket8',  XB=2.4,2.5,2.1,2.7,1.0,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
&OBST ID='Blanket9',  XB=2.4,2.5,2.7,3.0,0.3,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
&OBST ID='Blanket10', XB=3.9,4.0,1.8,3.0,0.3,1.2,COLOR='ORANGE',SURF_ID='Blanket'/
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&OBST ID='1Backrest', XB=1.8,1.9,2.1,2.7,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
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&OBST ID='1CL4',      XB=2.3,2.4,2.6,2.7,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
/CHAIR2
&OBST ID='2Seat',     XB=2.9,3.5,3.0,3.6,0.8,0.9,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2Backrest', XB=2.9,3.5,3.5,3.6,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
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&OBST ID='2CL2',      XB=2.9,3.0,3.5,3.6,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL3',      XB=3.4,3.5,3.0,3.1,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL4',      XB=3.4,3.5,3.5,3.6,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
/CHAIR3
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&OBST ID='3Backrest', XB=2.9,3.5,1.2,1.3,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL1',      XB=2.9,3.0,1.2,1.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL2',      XB=2.9,3.0,1.7,1.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL3',      XB=3.4,3.5,1.2,1.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL4',      XB=3.4,3.5,1.7,1.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/

&OBST ID='Bowl',  XB=2.0,2.4,3.2,3.6,0.2,0.4,COLOR='ORANGE'/
&VENT ID='Vent1', XB=2.3,2.4,3.5,3.6,0.4,0.4, COLOR='RED', SURF_ID='Fire', /
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Code scenario 5

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&OBST ID='TL2',   XB=2.1,2.2,1.2,1.3,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
&OBST ID='TL3',   XB=3.4,3.5,0.3,0.4,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
&OBST ID='TL4',   XB=3.4,3.5,1.2,1.3,0.2,1.2,COLOR='GREEN',SURF_ID='Table'/
/MATTRESSES
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&OBST ID='Mattress2', XB=2.5,4.3,3.2,4.0,0.2,0.5,COLOR='RED',    SURF_ID='Mattress'/
&OBST ID='Mattress3', XB=2.5,4.3,2.4,3.2,0.2,0.5,COLOR='BLUE',   SURF_ID='Mattress'/
&OBST ID='Mattress4', XB=2.5,4.3,1.6,2.4,0.2,0.5,COLOR='GREEN',  SURF_ID='Mattress'/
/Wardrobe
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/BOXES
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&OBST ID='Box9', XB=4.4,4.8,0.2,0.7,1.0,1.4,COLOR='ORANGE', SURF_ID='Box'/
/Curtains
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/BLANKETS
&OBST ID='Blanket1', XB=2.5,4.0,4.0,4.8,0.5,0.6,COLOR='ORANGE'SURF_ID='Blanket'/
&OBST ID='Blanket2', XB=2.5,4.0,3.2,4.0,0.5,0.6,COLOR='BROWN',SURF_ID='Blanket'/
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&OBST ID='1Backrest', XB=1.2,1.8,0.2,0.3,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='1CL1',      XB=1.2,1.3,0.2,0.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='1CL2',      XB=1.2,1.3,0.7,0.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='1CL3',      XB=1.7,1.8,0.2,0.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='1CL4',      XB=1.7,1.8,0.7,0.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
/CHAIR2
&OBST ID='2Seat',     XB=1.8,2.4,4.2,4.8,0.8,0.9,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2Backrest', XB=1.8,2.4,4.7,4.8,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL1',      XB=1.8,1.9,4.2,4.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL2',      XB=1.8,1.9,4.7,4.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL3',      XB=2.3,2.4,4.2,4.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='2CL4',      XB=2.3,2.4,4.7,4.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
/CHAIR3
&OBST ID='3Seat',     XB=1.0,1.6,4.2,4.8,0.8,0.9,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3Backrest', XB=1.0,1.6,4.7,4.8,0.8,1.6,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL1',      XB=1.0,1.1,4.2,4.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL2',      XB=1.0,1.1,4.7,4.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
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&OBST ID='3CL3',      XB=1.5,1.6,4.2,4.3,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/
&OBST ID='3CL4',      XB=1.5,1.6,4.6,4.8,0.2,0.8,COLOR='BLUE',SURF_ID='Chair'/

&VENT ID='Vent1', SURF_ID='Fire', XB=2.5,2.6,3.2,3.3,0.6,0.6, COLOR='RED'/
```

8.7. Questionary

1. Are there any smokers living in your household, and if so, how many?

    - No
    - 1
    - 2
    - 3
    - 4 or more

    Do you smoke indoors?

    - Yes
    - No

2. For cold weather, what method do you use to heat your home?

    - Air heater
    - Stove
    - Heating
    - Other(specify)

3. In your kitchen, what method do you use for cooking?
    - Glass ceramic hob
    - Gas cooker
    - Other(specify)
4. Do you use candles on a regular basis?

    - No
    - Yes, when the light goes out
    - Once or twice a week
    - Daily

5. What type of boiler do you have in your home?

    - Gas
    - Butane
    - Electric

6. Do you store any of these products at home?

    - Painting
    - Bleach
    - Glue
    - Gasoil
    - Cardboard

If you store any, do you have any control over their storage?

- Yes
- No

7. Did you witness a fire?
   - No
   - Yes, at home
   - Yes, in my building
   - Yes, in my street

8.8. Relationship with the SDGs

This work relates to the following SDGs

3. **Good Health and Well-Being.**

Both fuel poverty and fire risk are closely related to SDG 3, which seeks to ensure health and well-being for all people in the world.

Energy poverty means that people lack some energy services, such as heating, which can pose a risk to the health of some people, and it also means that those living in energy poverty have precarious living conditions if their homes are poorly lit or at a bad temperature. These problems, as already explained during the work, lead to the use of electrical appliances with a high risk of fire.

When living in fuel poverty, it is more likely that the housing conditions are less adapted and lack emergency exits or there are elements that hinder evacuation or the action of emergency services.

In addition to all this, there is also the psychological impact on people living in this type of situation, as they know the risks they are subjected to on a daily basis, but due to a lack of resources they have no choice. There is also the psychological damage suffered by people whose homes have been set on fire due to the loss of their hard-earned material possessions and, in the worst cases, the damage to the affected family members.

4. **Quality Education.**

Fuel poverty can affect quality education, as the lack of some services such as electricity and therefore the internet can cause children to have limited opportunities to learn.

In addition, this work aims to provide good guidelines for this sector of the population affected by fuel poverty so that they can minimise the risk of fire. It is known that this sector of the population will continue to access sources that have a higher associated risk because they are cheaper, but it is intended that they do so with extreme caution and if possible change some habits that increase this risk, such as smoking outdoors or storing flammable products in suitable places.

7. **Affordable and clean energy.**

This SDG is related to work since most of the fire risks associated with energy poverty are due to the use of more polluting energy sources, since they are the cheapest. In addition, this sector lacks safe access to the electricity grid, as the installations are often in poor condition or have been connected illegally, so that safety regulations are not followed.

Promoting clean and sustainable energy would make it more accessible to these families, which in turn would reduce the risk of fire associated with the use of electrical appliances and the sources mentioned above.

10. **Reduced Inequalities**.

The work is related to SDG 10 since a family living in fuel poverty means that they have difficulties in accessing certain energy sources, which leads to social inequalities. In addition, this energy poverty leads to another inequality which, as we have seen in this work, is the risk of fires to which they are subjected. Although some factors that accentuate this risk are very difficult to combat and would require a high level of investment and a lot of time, there are some others that are very easy to eliminate and could be solved with good education for these sectors of the population.

11.**Sustainable Cities and Communities.**

By trying to reduce these dangerous energy sources and facilitating access to safer and more sustainable sources of energy, the sustainability of these communities would be promoted, and by properly educating these sectors not to engage in reckless behaviour, the number of fires would be reduced, which in turn would have an impact on fire emissions, all of which would benefit the progress of sustainable societies and cities.

9. References

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