Chapter

# New Trends in Industrial Equipment for the Improvement of Asphalt Roofing Process

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## Abstract

Roofing techniques are the key for weather resistance and energy efficiency of buildings. Installing asphalt roofing rolls is one of the most popular roof protection methods. This is usually carried out manually. Workers apply heat to the rolls by means of burners. Operators must follow quite a few steps to roof: place the rolls on the ground, unroll, apply energy, and secure. From 20 to 25 rolls per day can be installed by an operator using this manual procedure (200–250 $m^2$). So, the fact that manual installation means such a reduced work capacity has pushed the development of industrial equipment. Besides, requirement for reduction of $CO_2$ emissions is forcing to develop systems that optimize the fuel consumptions or even to replace fuel burners by other types of electric heating devices. In this chapter, a review of the state of the art and market of equipment for accelerating asphalt roofing process is presented. A detailed description of some systems and patents is given. The main geometric, physical, and performance parameters will be described and compared. Two new systems based on torches and infrared heating show double installation speed that is the usual manual roofing rate.

**Keywords:** asphalt roofing, asphalt coating, bituminous sheet, lightweight trolley mechanism, infrared heaters, fuel burners

## 1. Introduction

Historically, construction has been a wasteful process that sometimes could be automated or anyhow upgraded. Particularly, the manual installation of asphalt roofing rolls has several efficiency issues and its susceptible of being developed such as: safety and workers' health, installation speed, emissions, and quality of installation.

Currently, as experts in the field can ensure, installation of asphalt roofing rolls is usually carried out manually. The operators must accomplish several tasks: choosing the position of the rolls, calculating how many rolls are needed, getting them unrolled on the ground, activating rolls bonding with the surface by heating them, and ensuring everything is glued tight. In addition, during manual installation, there is not any heat control or measuring, since heat torches are hand-controlled by the workers themselves, which sometimes leads to an excessive application of heat and energy loss. Using the explained current method, an average of 20–25 installed rolls per worker a day is only achievable. The poor work capacity of manual installation has uncovered the necessity to look for new systems or equipment that makes the process easier and more efficient.

Most of the devices designed to assist in these tasks are based on one or more torches. $SO_2$ and $CO_2$ emissions generated by gas burners must be diminished as much as possible. Environmental administrations are heeding roofing processes in order to reduce emissions. Emission factors in the manufacturing of asphalt [1] were devised by the Asphalt Roofing Manufacturing Association (ARMA). A measurement of 75.2 kg $CO_2$ per roll was done [2] and determined that the responsible for the greater number of those emissions was the installation stage. Six million tons of asphalt per year are used in this installation process, which produces a large amount of $CO_2$, $SO_2$, and other non-eco-friendly emissions.

An alternative option to gas burners [3] could be infrared heaters, but a high electrical power source must be available, so its usability is limited. Therefore, the most polyvalent solution is to optimize heat transfer from torches, burners to asphalt rolls and, thus, gas expense.

Roofing workers' health must also be secured besides installation speed and gas consumption. Workers do not usually employ safety prevention equipment at the expense to improve their speed while performing manual installation. This practice also increases the risk of accidents. A proper way to prevent injuries is to design systems and equipment for efficient operation [4]; fatalities and occupational illnesses also can come from a non-designed bad posture during manual roofing.

In this book chapter, a state of the art is made of the main patents and products for the improvement and assistance in the installation of asphalt roofing rolls, based on both torches and infrared heating. Then, two new systems based on torches and infrared heating are described and compared with previous systems. This novel equipment permits the operators to work in more secure conditions avoiding occupational injuries. It must be lightweight and usable on any class of roof, will increase installation speed, and optimize gas and electricity consumption. Consequently, this new equipment even supposes a human factor improvement because while working, humans are also an emission source (eating, creating waste, using electricity, etc.), so, if the working time is reduced, so will be worker's impact.

In contrast, infrared heaters can supply steady heating power, free from the need of fuel burners. Infrared heaters are electrically powered and driven. That power could have been obtained from green energy sources, and also it is cleaner and safer for operators in their workplace. Enhancement of infrared heaters can also imply large heat transfer rates [5].

The designed new equipment is based on a trolley, which ensures the installation of asphalt in a cleaner, faster, and safer way. One version of the devices incorporates eight infrared heaters located radially and longitudinally around the asphalt roll, while the second version has a set of five parallel torches located in front of the roll to heat the asphalt up. Operators do not have to lift or unroll asphalt rolls, since they are directly placed on the floor and unrolled by auxiliary wheels as the same operator controls heat application. This conciliates a uniform and continuous roll heating to properly stick onto the ground, at the same time it keeps unrolling. Moreover, to guarantee the adherence of the asphalt in those places where the rolls overlap, the equipment counts with two small compaction drum rollers in both lateral sides.

The mechanical and thermal design of both models is presented, comparing heat transfer efficiency with computer fluid dynamics (CFD) simulations and calculations. Furthermore, some photos of the prototypes and operational tests are provided, demonstrating the advantages of its use rather than using manual installation. A comparison of these new systems with previous patents and commercial equipment is given in conclusions section.

## 2. State of the art

There can be found several inventions to assist in the installation of asphalt coating, most of them based on one or more torches. In 1993, the patent ES 2041192 – entitled "Method and apparatus for applying a bituminous sheet to a substrate" [6] relates a preheated constant temperature roller (close to 300°C), wherein bituminous sheets slide toward their installation (**Figure 1**).

The patent DE-A 1652399-Device for heating and gluing a rolled material on a substrate [7] was published in 1971 (**Figure 2**). This patent claimed for a mechanism that allows the installation of a sheet by the application of heat to it. It includes a series of torches placed along all the bituminous sheet width. It has some disadvantages, for example, the direction of operator walking is backward, and this may cause falls from a certain dangerous height. Also, it prevents the operator from seeing what is happening behind his back, which could cause injury to other operators or apply the sheet on material remains causing fissures. Also, the heat application on the sheet is done from a great distance with respect to the installation point, and the bitumen primer that must be put on the substrate where the sheet is installed does not heat up. Moreover, the linear heating of the bituminous sheet causes that heat must be applied for a longer time, since it heats up from room temperature. Besides, there is only one general gas-regulating valve, which causes a perceptible pressure drop between the first torch and the last one. Last, the device could be too long, making it difficult to transport and place it on the construction site.

The patent US 4725328 [8]—a single ply roofing applicator, from 1988, presents the same characteristics commented for the previous mechanism, differing only in two aspects. First, two torches are incorporated, placed perpendicular to the substrate, which are placed at both ends to promote adherence in the overlaps. Secondly, two rollers are added to each side of the mechanism to improve adherence to the overlaps by means of pressure against the substrate. It also shares some disadvantages with the previous mechanism, such as backward direction of operator walking, the linear heating of the bituminous sheet, and that there is only one gas-regulating valve.

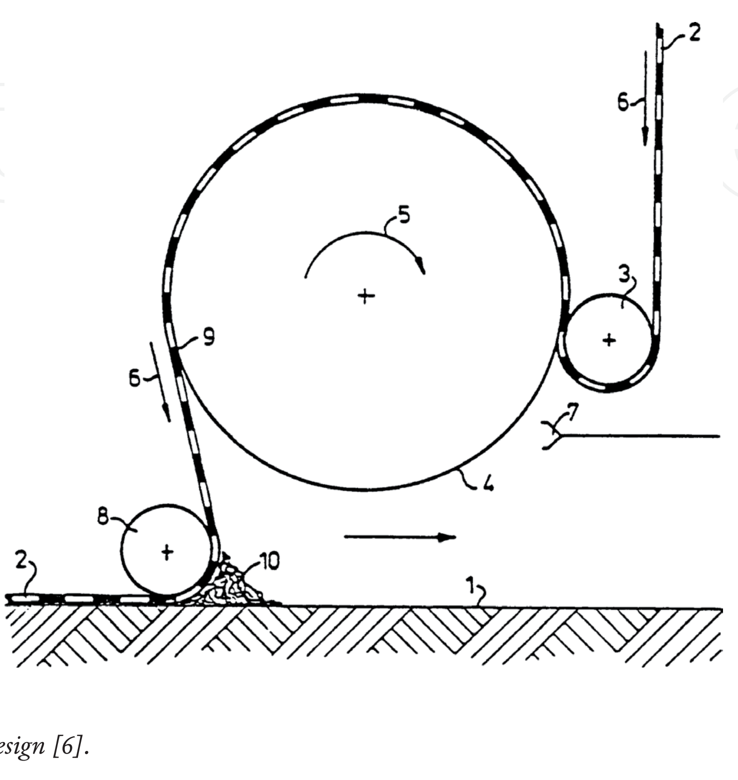


**Figure 1.**
*ES 2041192 patent design [6].*

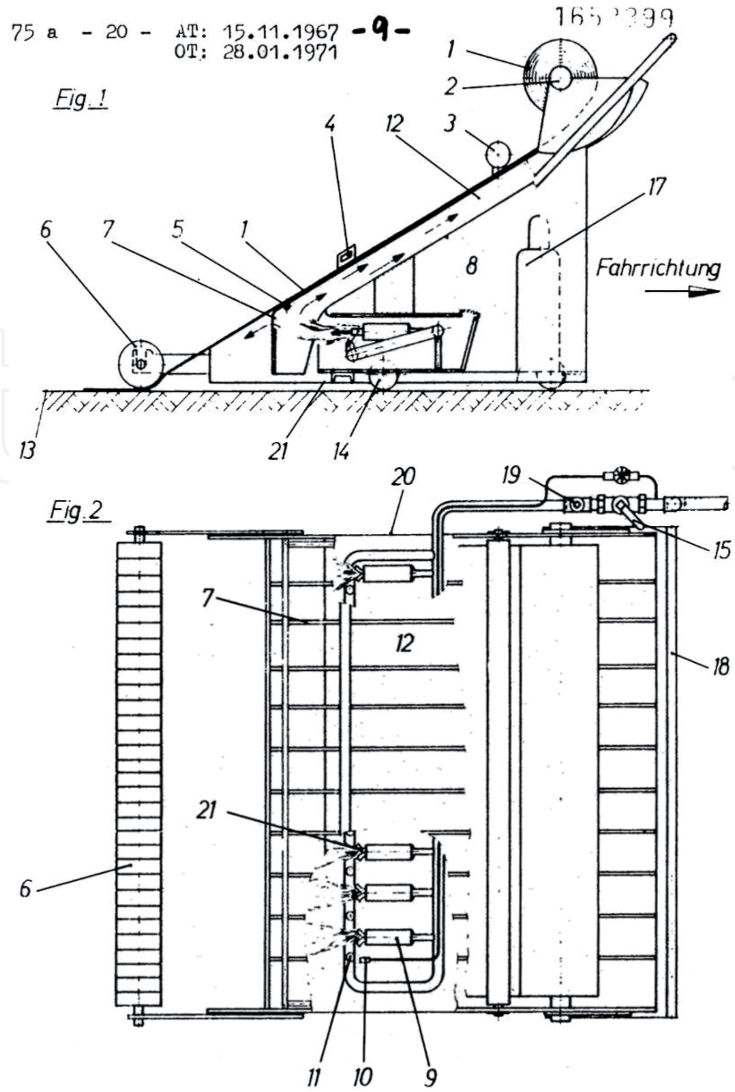


**Figure 2.**
*DE-A 1652399 patent design [7].*

In 1982, the patent US 4354893 [9]—combination roofing material unrolling and heat applying apparatus, was published. This patent describes a lighter design than the described above, since it dispenses with the roller system and the base to support the gas cylinder. It incorporates an extra handle, which permits the torches to get toward the roll as it unwinds, therefore enhancing heat application. As the previous ones, the direction of operator travel is backward, the warming is done from room temperature, that there is only one gas-regulating valve and, in addition, the unrolling system of the bituminous sheet is carried out by means of a bar incorporated into the axis of the roll. This is not efficient because the bituminous sheet is flexible and tends to deform. The appearance of folds that can cause problems for water filtration is favored.

Other significant patent is US2006037710 [10]—a membrane applicator. It varies in two aspects with respect to the previous patents: a gas cylinder is supported by a base, and it includes the incorporation of a roller on one flank of the mechanism to guarantee the adherence of the overlap. Their downsides, again, are the reverse direction of travel, but also heat must be applied for a longer time since it heats up from room temperature, and to have only one gas-regulating valve, which is also a pitfall.

As well as patents, it is interesting to analyze what commercialized mechanisms exist. Among them, Seal-Master 1030 (Schäfer Technic GmbH) [11] is very relevant. It is a machine that allows the continuous installation of bituminous sheets in civil engineering works. It is mainly characterized by the large roller on which the bituminous sheet roll is placed for unwinding. This mechanism is not suitable for use on roofs due to its great weight and the use of sheets of greater length than those marketed for waterproofing roofs. It also incorporates a base to place the gas cylinder that is used to supply the torches that are located in the lower part of the mechanism. Finally, the roller used to ensure adherence of the bituminous sheet throughout its width also stands out. On the Schäfer Technic GmbH website, it is indicated that the weight of the set is 660 kg, which makes this mechanism not easy to transport. A site crane would be needed to raise it to the roof, and overload problems on punctual spots of the roof could seriously damage the structure of the construction.

Unify-ER (RES Automatisation Contrôle) [12] is characterized by its remote control (controlled by an operator) and by a greater number of mobile mechanisms than the rest of the systems, which makes this mechanism considerably increase in weight and makes it difficult to use on roofs. It also has a frame on which to place the gas cylinder, a system of rollers to improve the unrolling of the bituminous sheet, and some side stops that guide the roll and prevent folds from appearing when the sheet is placed on the substrate. It is based on the patent US 8887782—membrane applying apparatus, from 2014. The company claims for an installation speed of 1 m/min, which means a rate of 18 rolls per hour employing two workers. This leads to an installation of 480 $m^2$ a day per person.

The principal drawbacks of these two systems are that they are too large to operate on small roofs, too heavy, and challenging to transport. In addition, they have an

| Feature to improve | ES 2041192 | DE-A 1652399 | US 4725328 | US 4354893 | US 2006/0037710 |
|---|---|---|---|---|---|
| Reverse travel direction | | x | x | x | x |
| Far away heat source | | x | | | |
| Heating from room temperature | | x | x | x | x |
| A single gas regulation valve | | x | x | x | x |
| **Feature to improve** | **Unify-ER** | **Seal-Master 1030** | **FORSTHOFF-P2** | **BITUMAT B2** | **Bitumenbrenner** |
| Reverse travel direction | | x | | | |
| Heating from room temperature | | | | | x |
| Excessive weight | x | x | | | |
| Very long mechanism | x | x | | | |
| Electronic components and batteries | x | x | | | |
| Does not seal overlaps | | | | | x |
| Exclusive use for overlaps | | | x | x | |

**Table 1.**
*Details of the characteristics to be improved in the different patents and commercialized products.*

electronic and battery system, which increases the possibility of having failures that prevent the continued use of the device.

On the other hand, the devices FORSTHOFF-P2 (Forsthoff GmbH) [13] and BITUMAT B2 (Leister Technologies AG) [14] can be found. They only serve to heat the sheets in the overlaps, which is an essential requirement for a good waterproofing of the roofs, but they do not heat the rest of the sheet.

And finally, there is Bitumenbrenner (Bamert Spenglerei GmbH) [15], which allows the entire surface of the bituminous sheet to be heated as it uses four individualized torches equally spaced between them, spreading across the width of the sheet. This system also needs the heat to be applied for a longer time, since it heats up from room temperature, at least two operators are required (one of them unrolls the sheet while the other applies heat to it), and it does not allow a correct overlap between sheets, this being the most important process in the installation of waterproofing.

**Table 1** presents main characteristics of previous state-of-the-art semiautomatic roofing systems. **Table 1** includes those features that should be improved or changed.

## 3. Recent developments

As seen in the state of the art, most systems are based on torches. The devices described above present a series of disadvantages. The main ones are an excessive weight, and the fact that they are used for very specific tasks (some only serve to fix the overlaps, and others precisely do not seal the overlaps well).

To overcome all previous limitations from **Table 1**, two novel prototypes have been designed, simulated, and tested with torches and radiators as heating devices. Heaters are fixed to a lightweight structure, which can be pushed forward by an operator, and which unfolds the roll as it heats up, with emphasis on the overlaps. The efficiency of both systems is compared, and the speed of installation is determined.

### 3.1 Infrared heating

The patent protecting these novel equipment is P201830702 [16]—entitled "Lightweight mechanism for the rapid laying of bituminous sheets in flat roof waterproofing." A more in-depth analysis can be read in [17]. The mechanism is based on a trolley that allows a quicker installation of asphalt roofing rolls, in a cleaner and safer way than manual installation, by using infrared heaters. The worker does not need to lift the rolls because they are laid on the ground. As the worker advances, he pushes the trolley and the roll is unrolled helped by an auxiliary wheel. Eight infrared heaters are located longitudinally and radially around the roll, as can be seen in **Figure 3**. This layout provides a continuous and uniform heating of the roll, improving its adherence to the ground. Moreover, two drum rollers have been placed in the laterals of the trolley to ensure the adhesion on the overlaps.

**Figure 4** shows the front, lateral, and top views of the design. The trolley (2) is pushed forward from the handle (1), whose height can be modified to suit the operator. The mechanism rests on four wheels (5) that allow the movement of the trolley. The rear-mounted wheels are locked in the movement direction to help maintain the installation direction. The asphalt roofing roll (7) is located inside the structure. The trolley keeps the roll in the desired position with two locating stops (6). Besides, there is an auxiliary wheel (8), placed in the longitudinally center of the roll, and at an optimum height, which transmits the pushing force to the roll.

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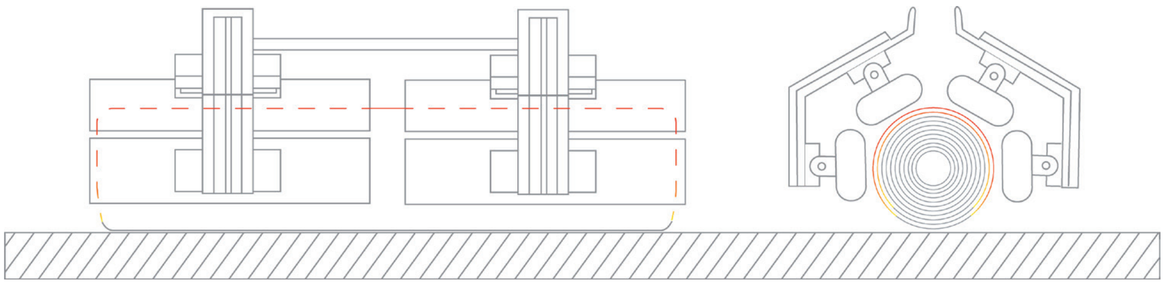

**Figure 3.**
*Design of the structure for the heaters [17].*

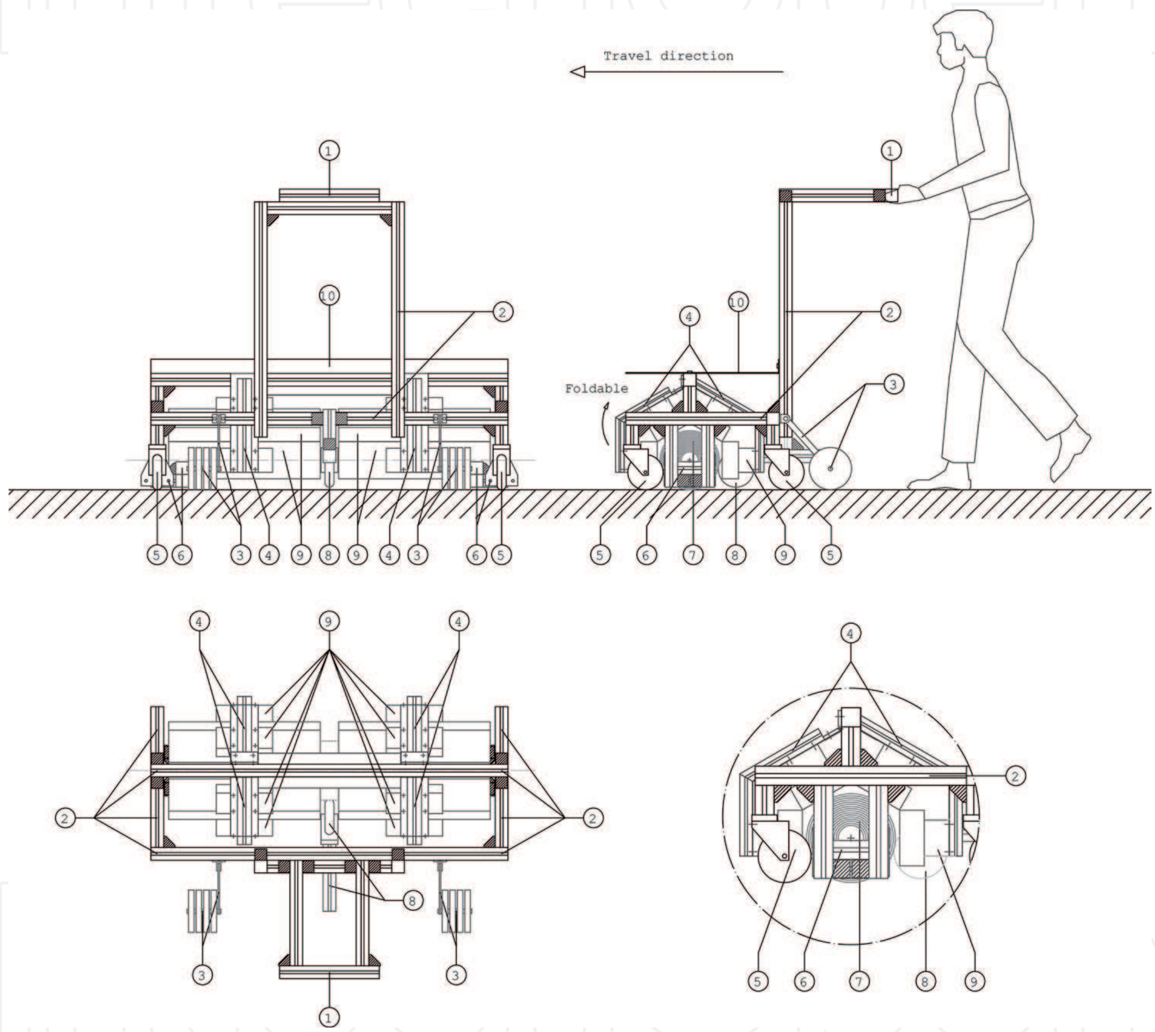


**Figure 4.**
*Front, lateral, and top views of the infrared heaters design [17].*

This causes the rotation movement of the roll, facilitating its unwinding. Two small drum rollers (3) improve the overlapping.

Al last, there are the eight infrared heaters (9) and the enclosure removable cover (10). A detail of the distribution of the heaters is also shown.

1200 W infrared heaters have been selected. The roll received a maximum power flux of 11,794 W/m$^2$. To determine the adequate heating up time for installing the first layer, a temperature selection choice was defined. On the one hand, the temperatures must be high enough along the external layer to bring most of the asphalt to a viscosity behavior point (140°C). But on the other hand, lower temperatures at the interlayer point are needed to avoid interlayer adhesion of the roll. Then, the top surface temperature must be much greater than 140°C, temperature must be at

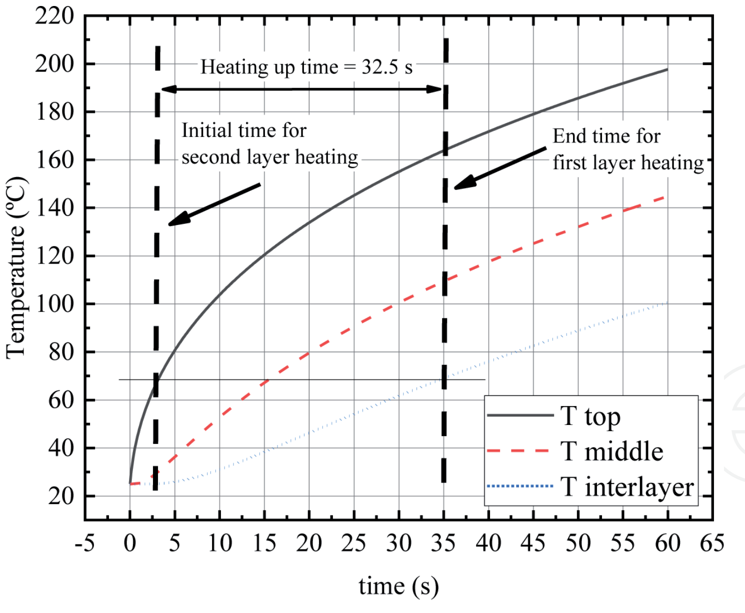


**Figure 5.**
*Temperature versus time of the top surface, middle section, and interlayer point of the roll [17].*

least 110°C at the middle section, and lower than 70°C the interlayer point. After 35 seconds of warming, the temperature is reached. Important to remark that when the installation begins, the operator has to pre-warm the roll for 32.5 seconds. **Figure 5** depicts the desired temperature profiles after heating for 35 seconds.

The time necessary to install the second and subsequent layers can be also calculated. After heating up of initial layer, the first–second interlayer temperature is 69.18°C. So, the heating up time for the second layer will be shorter because the layer is already preheated. As can be seen in **Figure 5**, after 2.5 seconds of warming, the outer surface of the roll is 69°C, the same temperature as the outer surface of the second layer at the end of the heating up time of the first layer. Thus, it will be needed to hold on for 32.5 seconds for raising the temperature of the following layer from 69 to 169°C. An average installation speed of 1 m/min, is demonstrated for 3 kg/m$^2$ rolls. This means more than the current manual roofing rate, around 400–420 m$^2$ per person a day.

Following the design and simulations, a prototype including infrared heater was assembled (**Figure 6**). The temperature criteria selected during thermal design were validated, and also the maximum temperature to prevent interlayer adhesions (below 60–80°C).

Finally, the equipment was tested outdoors. It was powered by a 14 kW diesel portable generator and pre-warmed for 2 minutes. Then, the installation began. One asphalt roofing roll was completely adhered to the ground, as shown in

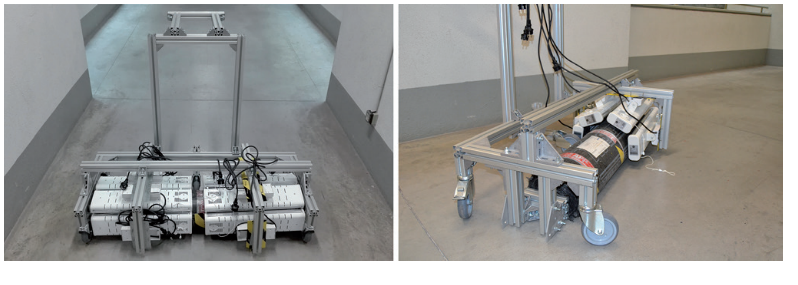

**Figure 6.**
*Infrared heating prototype.*

**Figure 7.**
*Outdoor installation test [17].*

**Figure 7**. Approximately 8 m of the asphalt roll were adhered after 8 minutes of warming, demonstrating the claimed installation speed.

### 3.2 Fuel burners

A second similar to the previous one model is presented, but in this prototype, gas torches are used instead of infrared heaters. A more in-depth analysis can be read in [18]. The structural design, as well as the analysis of the auxiliary wheel, is the same as in the previous model, but presents some slight differences, which can be seen in **Figure 8**. In this case, the trolley has two auxiliary wheels (5) instead of one at the optimum determined height. Moreover, a thermal insulation cover, preferably made of sheet metal and filled with insulating material (6), has been included, to improve the heat transfer.

The five torches (2) are aligned in parallel in front of the roll. The torches are connected in series with a flexible pipeline (8). Each burner can be controlled separately (7), but they are also controlled by a general regulator (10). An on/off manual valve (9) commands the activation/deactivation of the fuel burners. The gas comes from a pressurized propane bottle through a 10-meter-long flexible pipeline

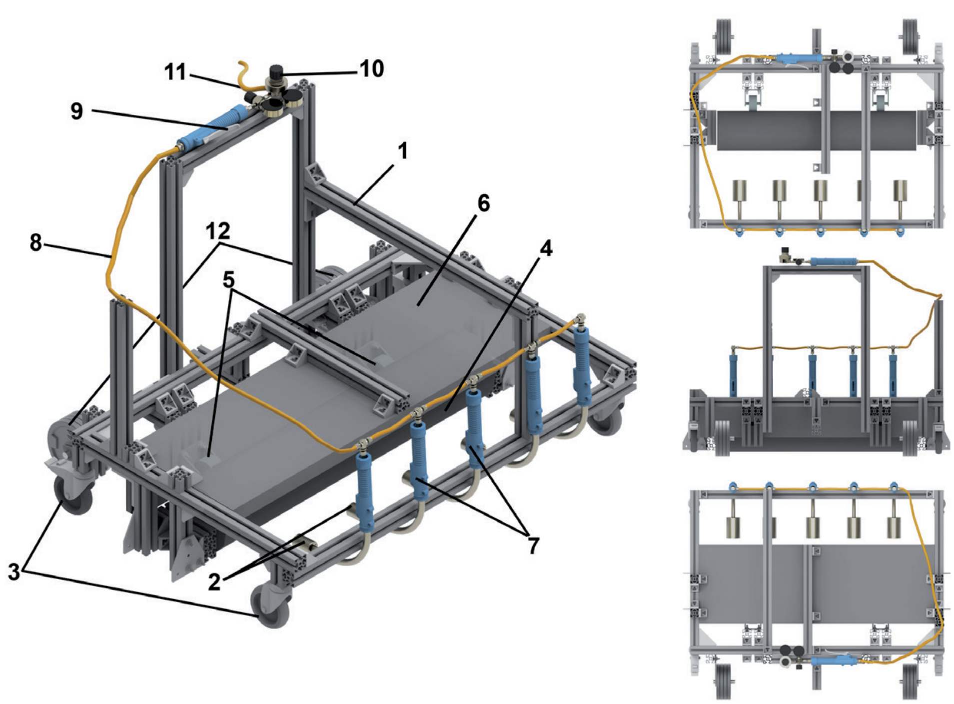


**Figure 8.**
*3D model of the fuel burners design [18].*

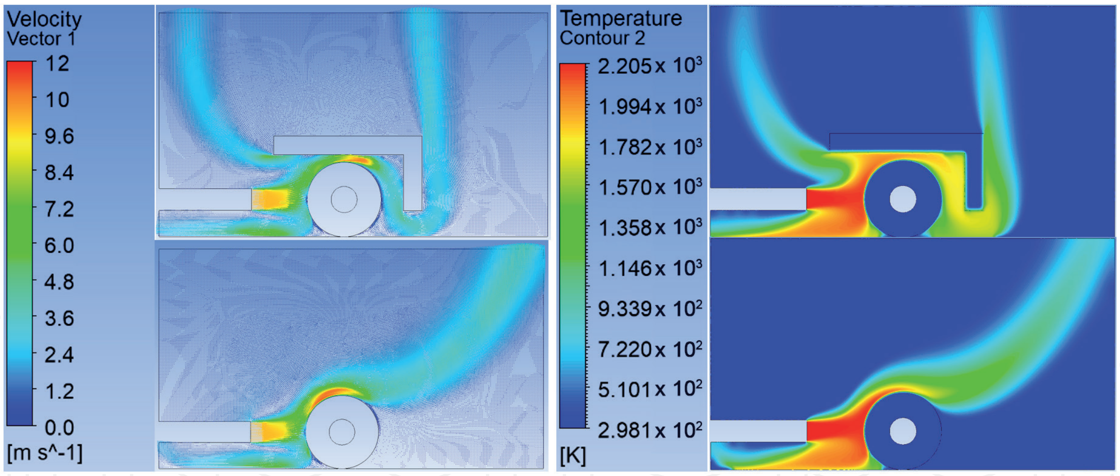


**Figure 9.**
*CFD results: Velocity (left) and temperature maps (right) with or without cover, time = 15 s [18].*

(11). There is very common that a worker just used a single torch, and thus, the heat flux is just applied in localized area. This leads to a nonuniform heating, inducing adherence problems in the overlapping areas. Using a layout with several torches, the heating uniformity can be improved. Gas pressure and fuel burner selection were calculated through a transient CFD simulation iterative process. They also determined the heat transfer to the roll.

In the proposed design, a thermal insulation is included to increase the efficiency of the heat transfer and to reduce the thermal losses by keeping the hot air close to the roll. A CFD analysis has been done to measure the effect of including this thermal insulation cover, and the results are shown in **Figure 9**.

Based on the design and the simulations, a prototype was assembled (**Figure 10**). The hot air flow speed and temperature were determined in laboratory preliminary tests. The propane consumption was also measured, being 2800 g/h of propane per torch.

The flame turns blue at the torch outlet, which means that air is about 1800–1980°C for propane [19]. In the yellow zone of the flame, the temperatures are lower, between 500 and 750°C. This can be seen in **Figure 10(left)**. In

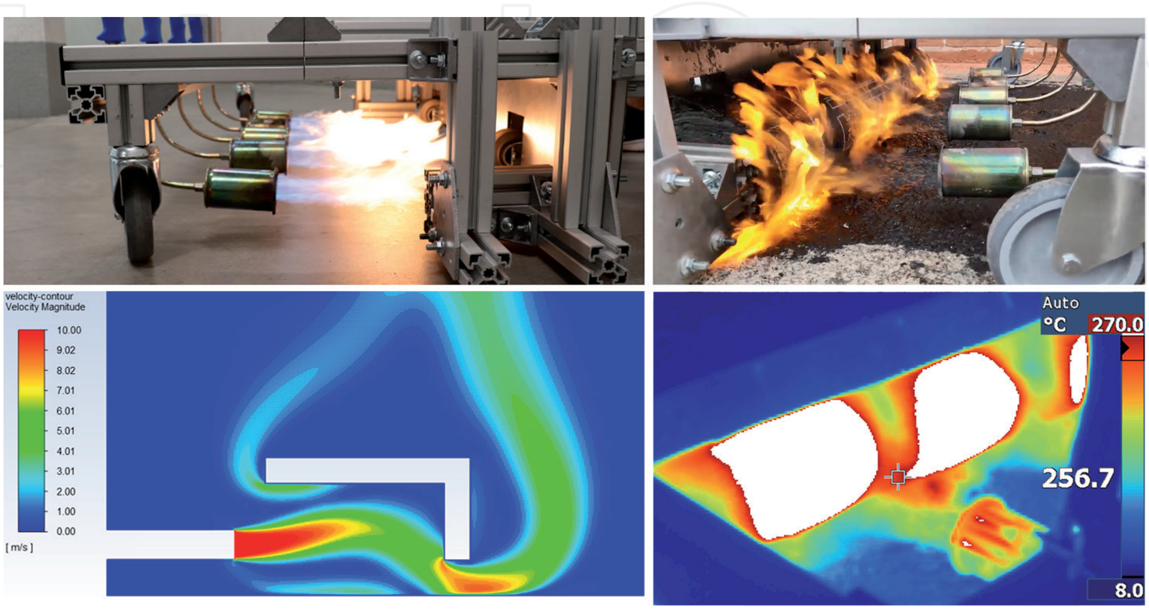


**Figure 10.**
*Flow and consumption test of the five torches (left) and temperature of the roll after 10 seconds of heating (right) [18].*

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**Figure 11.**
*Prototype and results of the asphalt rolls installation.*


**Figure 12.**
*Overlaps quality test and bond check.*

**Figure 10(right)**, the fuel burners operating at a pressure of 2.8 bar also can be seen, and the reached temperature after 10 second of warming on the roll surface. Almost half of the surface of the roll is above 200°C, which is high enough for a properly adherence.

Once the preliminary test was done, the outdoor tests of the installation of several adjacent rolls were performed (**Figure 11**). An installation speed of about 1.75 $m^2$/min was reached, with a 2.8 bar torch pressure and a consumption per torch of 2800 g/h of propane. A good adhesion was obtained on most of the surface of the bituminous sheet. In addition, the overlaps were adhered perfectly one over the other, ensuring isolation (**Figure 12**).

## 4. Conclusions

A state of the art of the main patents and commercialized products for the improvement and assistance in the installation of asphalt roofing rolls has been made, based on both torches and infrared heating inventions. Their main characteristics have been detailed and collected, as well as the aspects that would require improvement.

Later, two novel systems based on torches and infrared heating have been analyzed and described. The one with infrared heaters has demonstrated an installation speed of 1 m/min, on average, for 3 kg/m2 rolls, which leads to approximately 400–420 $m^2$ per person a day, and the one with fuel burners has reached an installation speed of 1.75 $m^2$/min for 3 kg/$m^2$ rolls, approximately 700–735 $m^2$ per person per day, more than double the usual manual roofing rate. A summary and comparison of the installation speeds are provided in **Table 2**.

This shows greater efficiency in the system with torches, although with radiators it also achieves more than the usual manual roofing rate. Using higher-power radiators, it could be equal to, and even to surpass, the torch model. But, there appears

| Device | Installation speed (m/min) | Installation speed ($m^2$ per person a day) | Installation speed (rolls per hour) |
|---|---|---|---|
| **Unify-ER** | 1 | 480 | 18 (two workers) |
| **Seal-Master 1030** | 2.5 | 1200 | 45 |
| **FORSTHOFF-P2** | 11 | — | — |
| **BITUMAT B2** | 0.8–12 | — | — |
| **Bitumenbrenner** | ? | ? | ? |
| **Infrared heating prototype** | 1 | 400–420 | 15–16 |
| **Fuel burners prototype** | 1.75 | 700–735 | 26–28 |

**Table 2.**
*Installation speeds of the prototypes and commercialized products.*

the requirement of electric generators, which in certain circumstances could be more complicated. Both have advantages and disadvantages and may be preferable for depending on what applications. Although the torch system may seem very polluting, by replacing the traditional manual method by the new system, work times are greatly reduced and larger efficiency is achieved, reducing total final emissions. In conclusion, the development of this type of systems can be very useful to improve the quality, safety, efficiency, and work time of asphalt roofing.

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## Conflict of interest

The authors declare no conflict of interest.

## Appendices and Nomenclature

| | |
|---|---|
| ARMA | Asphalt Roofing Manufacturing Association |
| CFD | Computer Fluid Dynamics |
| LPG | Liquefied Petroleum Gas |

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