

## DISPOSABLE PERSONAL PROTECTIVE EQUIPMENT VENDING MACHINE

### AUTOMAT VENDINGOWY DO SPRZEDAŹY JEDNORAZOWEJ ODZIEŹY OCHRONNEJ

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#### Abstract

The article presents the concept and structure of a prototype of a vending machine that can dispense disposable personal protection equipment (PPE) or other products with similar physical properties (size, weight) to be used in outpatient clinics, hospitals or beauty parlours, where special and effective protection against pathogens is required, particularly during the pandemic. Due to the difficult-to-predict and unspecified technical and on-site conditions for the installation and use of the device, the authors wanted to achieve autonomy by using a replaceable battery as a power source and large storage capacity of a product rack, at a limited size of the device. The machine operates on a contactless payment system (credit/debit card or NFC mobile payments) – to buy a gown, a customer just has to tap or wave their card on or over the card reader installed in the front wall of the cabinet. Purchased products are dispensed automatically, once the transaction has been approved. The vending machine is also equipped with a removable dispenser to better manage any waste generated. The prototype was comprehensively tested in accordance with the developed verification methodology, in cooperation with an entity interested in implementing the device.

**Keywords:** vending machine, disposable personal protective equipment, reliability, control.

#### Streszczenie

Publikacja przedstawia koncepcję oraz budowę prototypowego urządzenia (automatu vendingowego) do samoobsługowej sprzedaży jednorazowej odzieży ochronnej lub innych produktów o podobnych cechach fizycznych (wymiary, masa) dedykowanego do zastosowań w przychodniach, szpitalach, gabinetach kosmetycznych, gdzie wymagana jest szczególna i skuteczna ochrona przed patogenami, zwłaszcza w okresach nasilonego narażenia epidemicznego. Ze względu na trudne do przewidzenia i nieokreślone warunki techniczne i lokalowe instalacji i użytkowania urządzenia, celem autorów było uzyskanie autonomiczności dzięki zasilaniu elektrycznemu z wymiennego akumulatora i dużej pojemności magazynka urządzenia przy ograniczonych gabarytach. Zastosowano terminal realizujący płatności bezgotówkowe oraz automatyczne wydawanie odzieży po ich zaakceptowaniu. Wbudowano wymienny zasobnik ułatwiający zagospodarowanie powstających

odpadów. Wykonany prototyp poddano kompleksowym badaniom zgodnie z opracowaną metodyką weryfikacji, we współpracy z przedsiębiorcą zainteresowanym wdrożeniem rozwiązania.

**Słowa kluczowe:** automat sprzedażowy, jednorazowa odzież ochronna, niezawodność, sterowanie.

## 1. Introduction

There is a high turnover of patients, visitors, staff and customers in medical facilities, treatment rooms and beauty parlours. During periods of intensified transmission of pathogens, as in the case of SARS-CoV-2, there is a high risk of rapid and wide spread of diseases. However, medical facilities are never completely free from pathogens even when the risk of a pandemic is low, which means that all possible measures and safeguards against uncontrolled transmission of pathogens must be implemented (e.g. the obligation to wear shoe covers in hospitals). Recently, there has been a growing need for disposable isolation gowns to be worn in medical facilities, particularly by visitors. This, in turn, has called for the organisation of an effective disposable PPE supply and distribution system, and the use of vending machines, commonly used to dispense shoe covers, proved to be the best and, at the same time, the easiest solution. What is needed is just a standardised packaging in which PPE (e.g. isolation gowns) should be placed to be easily dispensed, and a good location, preferably at the entrance door, where persons entering the facility can in a matter of seconds buy the required item with cash or debit/credit card.

Vending machines [6, 12] are commonly used to dispense snacks, canned or bottled beverages [1, 7], small toys, souvenirs and other small objects. Disposable PPE is characterised by high volume at a relatively small weight, which requires developing a special solution for its distribution. Additionally, most vending machines dispense various products showcased to customers [3]. In the case of disposable PPE, only one product is sold, which means that the space typically used to showcase products can be used to stack more items, which, in turn, means less frequent refilling.

Researchers at the Łukasiewicz Research Network – Institute for Sustainable Technologies (Łukasiewicz-ITeE) conducted studies on controlled distribution, dispensing and transportation of products, bulk and semi-liquid materials, and gases. The research was commissioned by business entities and scientific centres and it led to the development of, among other things, a solution for controlled transportation, quality assurance and selection of goods in a machine industry [14, 13, 2]; an automated inspection line for glass products [4]; a paint robot and an in-salon hair dye dispenser [8, 11]; an erosion

testing device (abrasive dispenser) [10]; and a production line for cable insulators (superabsorbent dispenser) [9]. In each of the above-mentioned examples, problems of dispensing, transporting and positioning individual products for the purpose of optical quality control and maintenance, as well as precise metering or continuous dosing of semi-liquid substances and powders were solved.

The vending machine developed at Łukasiewicz-ITeE for Biovalley is designed for medical facilities and it enables safe, easy and effective dispensing of disposable isolation gowns right at the entrance. The researchers were asked to solve the problem of the vending machine volume-to-stacked product quantity ratio, which – in the case of the products for which the vending machine was intended – was not typical for vending machines on the market. A smaller vending machine dispensing one kind of a product lowers production costs and fees collected by the facility owner. Another problem that needed to be addressed was the power supply. A replaceable battery was used as a power source to avoid additional electricity costs. An adequate level of energy consumption (energy balance), guaranteeing that the timing of the battery replacement is consistent with the timing of vending machine restacking, was ensured. The vending machine was equipped with a system to collect used PPE and packaging. This is an important solution, not found in vending machines available on the market, which is in line with the principles of circular economy. The vending machine dispenses only one kind of a product, which limits transaction time and contact with the machine. Only contactless payments (credit/debit card or NFC mobile payments) are supported. This helps limit transmission of microbes and increase customer satisfaction (positive customer experience).

## 2. Concept of the vending machine

The designed standalone device had to comply with the following technical and performance requirements: capacity of the product rack – at least 250 products; card reader to allow debit/credit card payments; automatic dispensing of a product in no more than 2–3 seconds after purchase; and autonomic power supply enabling all products to be dispensed.

The concept of the disposable PPE vending machine is presented in Figure 1. Isolation gowns packed in cylindrical packaging tubes made of thin

plastic are stacked in the top part of the machine (product rack). At the bottom of the product rack, there is a rotating drum with sockets for individual packaging tubes with isolation gowns to which the product purchased is dropped. Then the drum rotates and dispenses the product to the pick-up tray. A contactless payment device (card reader) is installed in the front wall of the vending machine. The vending machine's control system and actuators are battery-powered. The use of an autonomic battery as a power source means that the machine can be placed in any

location, even in places where no electricity power supply is available. The designers of the prototype assumed that isolation gowns would be placed in two stacks (columns) to better use the product rack space and, at the same time, reduce the size (depth) of the machine, which is just slightly bigger than twice the length of the individual packaging. As a result, the machine can be put in a small room or hallway. Instead of a product showcase, descriptive information about the product was placed on the front wall of the cabinet.

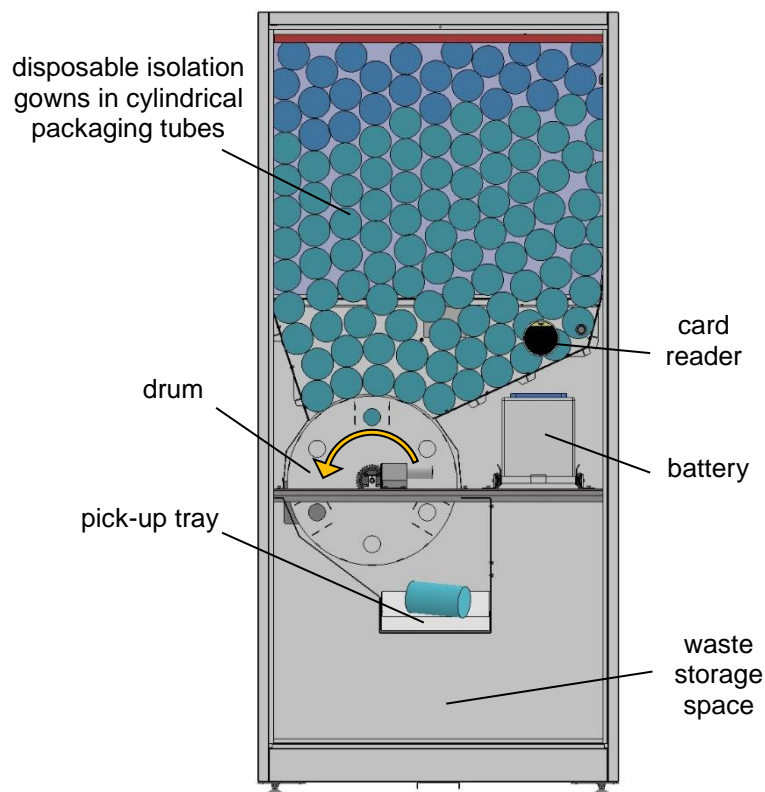


Fig. 1. Concept of the vending machine

The adopted concept assumes equipping the machine with integrated containers to store used gowns and packaging. The bottom part of the machine, which – for ergonomic reasons – would have been difficult to use otherwise, was designed for this purpose.

### 3. 3D model and documentation of the vending machine

The CAD 3D model was developed based on the adopted technical assumptions and concept of the vending machine. The model built in the CAD Autodesk Inventor system [5] allowed the spatial geometric and kinematic analysis of the adopted structural solutions. The model of a complete vending

machine with a visible internal structure is presented in Figure 2, and the elements enabling its automatic operation are presented in Figure 3.

The vending machine has a form of a rectangular cabinet in a metal casing (1), permanently closed on five sides; in the front wall there is a product inlet door (2), a card reader (3) and a service door. At the bottom of the front wall, in the centre, there is a pick-up tray (5) to which purchased gowns are dispensed. On each side of the pick-up tray there are slots for used gowns and packaging tubes (6). The pick-up tray and used gown and packaging tube slots are installed in a drawer, which plays the role of a waste bin (7). Disposable isolation gowns packed in cylindrical plastic packaging tubes (8) are placed on the product rack in two stacks separated by a moveable partition wall. At

the bottom of the rack (9) there are two slanted steel plates which enable the purchased product to easily slide to the middle and into a socket in the drum (10) closing the product rack from the bottom. The sockets are located in two rows – one closer the front wall of the cabinet under the front stack of plastic packaging tubes on the product rack, and the other closer to the back under the back stack. In each row there are six sockets in total (60° rotation). The drum rotates thanks to an electric motor with a shaft (11). Under the drum there is a dispensing chute (12), tilted towards the front wall of the cabinet, through which the purchased product is dispensed from the drum socket to the pick-up tray. The electric motor is powered by a battery (16) and controlled by an electronic controller (17). The product rack sensor detects a low level of product stacking, which indicates the need to refill the vending

machine. Drum position sensors (15) identify the indexed angular position of the drum. The drum rotates by 60°. The drum optical sensor checks whether a tube has been dropped into a correct drum socket. The product dispensing time  $t_p$ :

$$t_p = \frac{\alpha}{\omega} = \frac{\frac{\pi}{3}}{\frac{\pi n}{30} \frac{z_1}{z_2}}$$

where:

$\alpha$  – incremental rotation of the drum,  $= \frac{\pi}{3}$ ,

$\omega$  – angular velocity of the drum,  $\omega = \frac{\pi n}{30} \frac{z_1}{z_2}$ ,

$n$  – rotating speed of the gear motor, 12 r/min,

$\frac{z_1}{z_2}$  – transmission ratio,  $z_1 = 12$ ,  $z_2 = 36$ ,

is 2.5 s, in accordance with the adopted requirements.

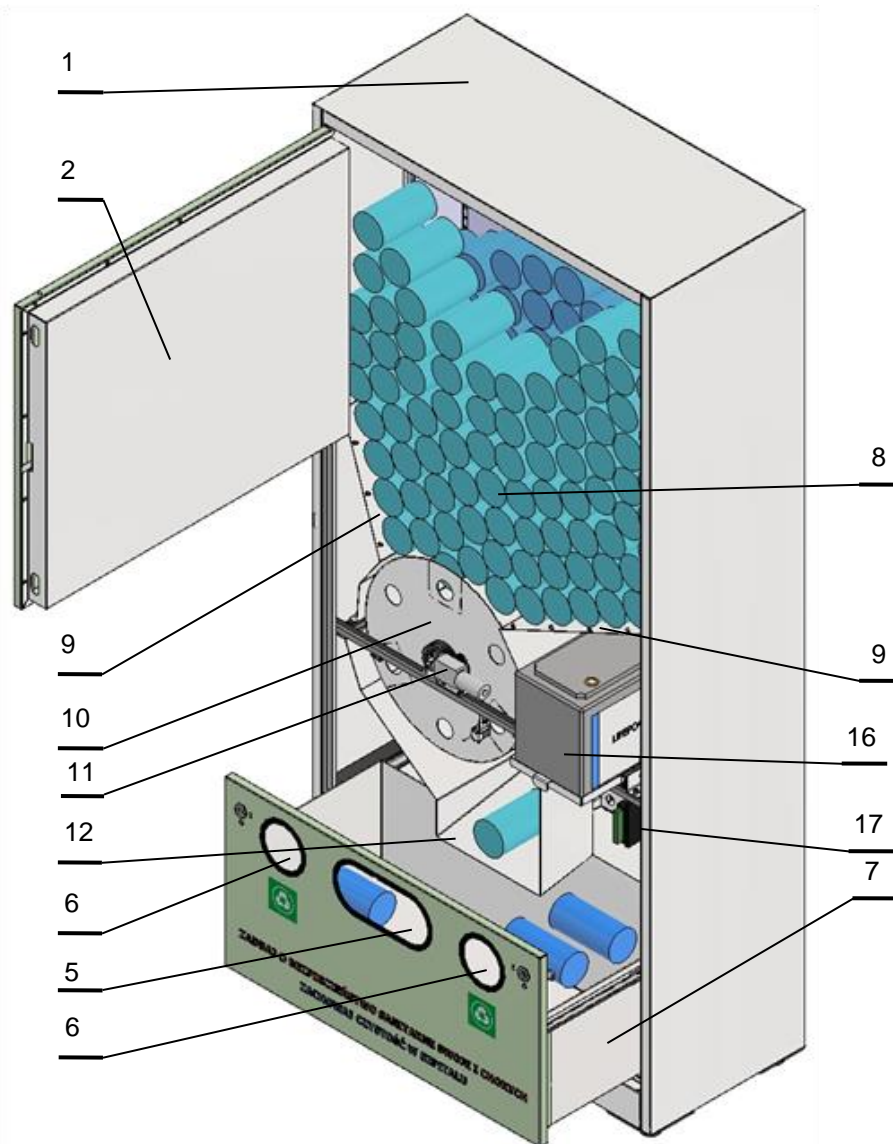


Fig. 2. CAD 3D model of the vending machine (general view): 1 – casing (cabinet); 2 – product inlet door; 5 – pick-up tray; 6 – slots; 7 – waste bin; 8 – products in cylindrical packaging tubes; 9 – bottom of the rack; 10 – drum; 11 – electric motor with a shaft; 12 – dispensing chute; 16 – battery; 17 – electronic controller

The vending machine can be filled with products after opening the product inlet door (Figure 5). First, products are stacked at the back and then at the front. Once the product inlet door is closed, the machine is ready to use. A customer activates the controller by pressing the button and making a contactless payment. This automatically activates the electric motor and rotates the drum. The drum makes so many 60 degree rotations as required for the sensor (14) to detect the presence of the product in the drum socket. When the machine works correctly, only one rotation is enough. After rotation, the product is dropped from the socket in the drum to the dispensing chute and to the pick-up

tray (5). After unpacking the gown, a customer can dispose of the packaging by placing it in the inlet hole (slot) at the bottom of the front wall. The other slot can be used to dispose of used gowns. The waste bin is attached to the sides of the cabinet with drawer slides, which means that all rubbish can be easily removed. Actuators and the card reader are powered by battery which stores enough electricity to keep the vending machine working for 18 days and dispense all products loaded (250 pieces). When the battery is flat (which is signalled automatically), it can be replaced with a charged one after opening the service door.

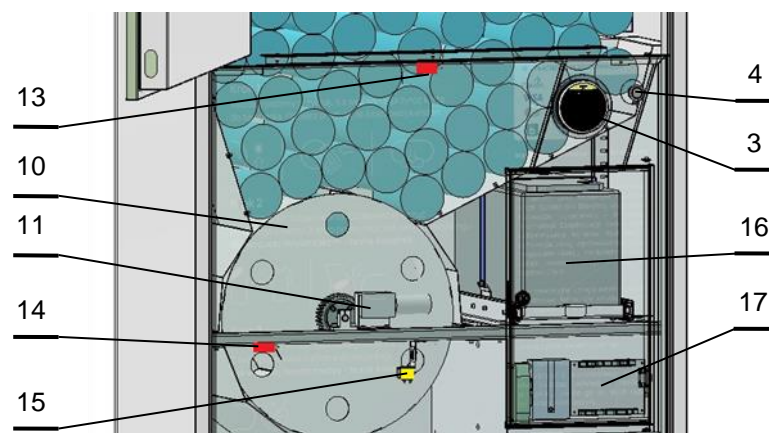


Fig. 3. CAD 3D model of the vending machine (automation elements): 3 – card reader; 4 – activating button; 10 – drum; 11 – electric motor with a shaft; 13 – product rack sensor; 14 – drum sensor; 15 – drum position sensor; 16 – battery; 17 – electronic controller

#### 4. Control system

The operation of the device is controlled by an electronic sensor, the block diagram of which is presented in Figure 4. The controller:

- controls the rotation of the drum based on the signals from sensors 14 and 15 and from a card reader (3) to properly dispense gowns;
- controls the inventory level using signals from sensor 13; and
- warns of a low product stacking and battery levels by sending an SMS.

The controller also controls the proper operation of the machine and manages battery electricity consumption; blocks the possibility of dispensing products that have not been paid for; and minimises the risk of accepting payment without dispensing a purchased product (this risk cannot be completely eliminated because it is impossible to exclude the potential failure of the machine after payment approval).

The control software verifies the proper sequence of sensor signals. This helps detect any inaccuracies and potential failures, e.g. absence of sensor signals,

damaged DC motor, drum block, product getting stuck in the dispenser. If such problems occur, an SMS notification is sent to maintenance workers. Such notifications are also sent when inventory levels are low. In such a case, once the signal from a relevant sensor has been confirmed five times in consecutive product dispensing cycles (to avoid any false alerts), maintenance workers will receive a notification reading: *ALERT: restack products*. The SMS notification module used was selected because it is reliable and characterised by low electricity consumption (approximately 0.005 A). For reasons of energy efficiency, the module was also used to measure and analyse battery charge level. In a standby mode, the main controller may use less electricity. Notification reading: *ALERT: replace batter* is sent when battery voltage drops to approximately 12.7 V and stays at this low level for at least 15 seconds. This value was selected to allow the battery to work for about three more days before the built-in battery management system (BMS) completely cuts off power supply. Theoretically, the use of a 100 Ah battery allows the machine to work for the maximum of 18 days (approximately), at the average electricity consumption of 0.23 A in a standby mode.

However, in practice, this period is a bit shorter (16–17 days), because, realistically, the available battery capacity will be lower than 100 Ah, and electricity consumption may also vary over time and

depending on the place of installation. This can be connected, among others, with higher electricity consumption when payment is made, notification sent, and product dispensed.

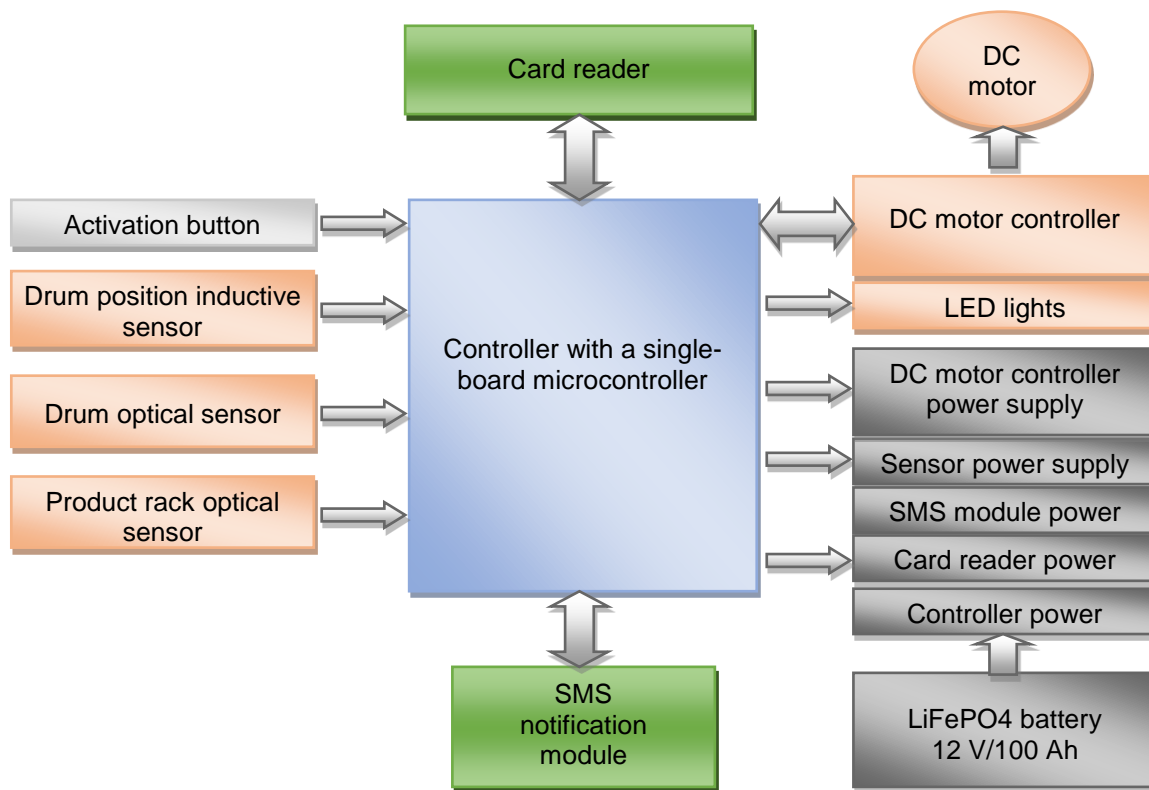


Fig. 4. Block diagram of the control and power supply systems

As shown in Figure 4, the controller manages battery electricity consumption. Electricity consumption is not monitored only in the case of the SMS notification module. All other components of the control system are enabled and activated only when the payment is made and product dispensed. This means that the optical sensors and the inductive sensor consume approximately 0.05 A each (0.15 A together). With the use of an additional activation button the machine wakes up from the standby mode. This button also unblocks the card reader, provided that a product is already in the drum socket. The LED illumination of this button also informs the customer whether or not the vending machine is fully operational – a continuous light indicates operability, while pulsing light means that the machine is faulty or empty.

When activated, the card reader consumes 0.35 A of electricity on average. Leaving it active would shorten the battery life. Therefore, after one minute, the card reader is blocked by the controller and goes into standby mode. Unfortunately, even in standby, the card reader consumes a lot of electricity (0.20 A) and

further electricity use reductions are impossible. In practice, completely cutting off the card reader power supply when the machine is not in use is not possible. This is because it takes 1.5 minute to activate it after a long period of idleness. Therefore, the card reader is the main component that determines the maximum operating time of a battery-powered vending machine.

## 5. Prototype verification

The prototype was built based on the adopted assumptions, developed model and technical documentation (Fig. 5). The prototype was equipped with a complete set of control instrumentation and software to verify the correct operation of the individual units and software controlling the automatic implementation of functional procedures.

The verification and functionality tests were carried out under real operating conditions [15]. Particular attention was paid to reliability of product dispensing (from a product rack to the drum and from the drum to the pick-up tray). The geometry of the bottom of the product rack and the size of the drum sockets were modified. The changes eliminated the

problem of occasional blocking of the collecting mechanism, improved the reliability of product collection from the product rack, and helped to dispense all products stacked. The dispensing chute was reshaped to ensure ergonomic positioning of the product in the pick-up tray. The bottom drawer (waste bin) was equipped with full-extension slides to enable easier collection of used gowns and plastic packaging tubes. Weights were mounted in the lower part of the machine – they lower the position of the centre of

gravity of the machine and position it better. The maximum operating time of the 12 V/100 Ah battery was tested. Dispensing all products used 2 Ah, which meant that the vending machine could remain on standby for about two weeks. Emergency control procedures were designed and introduced for uneven stacking of products on a product rack, dispensing errors, sensor failures or operation when a nearly flat battery is left to stand. Tests allowed the determination of flat battery notification thresholds.



Fig. 5. Prototype of a vending machine: a) at the time of stacking, b) after mounting at a medical facility

A verified prototype was placed in a medical facility (Figure 5b). The results of verification and field tests show that the developed device complies with the main requirements adopted at the concept stage.

The original structural solution of the vending machine developed at Łukasiewicz-ITeE and the entire concept of the device are the subject of a patent application and they are protected by intellectual property rights [16].

## 6. Summary

A prototype of a disposable personal protective equipment vending machine for facilities where procedures to prevent the spread of pathogens are in place and in use was designed and developed at Łukasiewicz-ITeE. The concept and the modus operandi of the machine were developed and formulated in cooperation with and as commissioned by a manufacturer and supplier of disposable personal protective equipment. The vending machine can dispense one product

type only, which, despite the limited size of the device, allows many products to be stacked. In the developed solution, an autonomic battery power supply and a card reader for contactless payments are used. The functional tests of the prototype confirmed that the functional parameters assumed at the concept stage were achieved and they revealed the potential for further improvement, particularly as regards the adaptation of selected structural solution to potential mass production. The developed and verified prototype, with a strong scientific foundation, may be an important step in the development of special purpose vending machines and a starting point for building similar scalable and customisable devices. Test results show that the stiffness and repeatability of the packaging (dents) have a major impact on the automatic dispensing process, which means that maintenance staff need to be very careful when stacking products as instructed. The original structural solutions developed at the Łukasiewicz-ITeE are the subject of a patent application.

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