Interdisciplinary Congress of Renewable Energies - Industrial Maintenance - Mechatronics and Informatics
*Booklets*

RENIECYT - LATINDEX - Research Gate - DULCINEA - CLASE - Sudoc - HISPANA - SHERPA UNIVERSIA - Google Scholar DOI - REDIB - Mendeley - DIALNET - ROAD - ORCID

# Title: A review of open-source ventilators for COVID-19

**Authors:** ESQUEDA-ELIZONDO, José Jaime, JIMÉNEZ-BERISTÁIN, Laura, MIRANDA-PASCUAL, María Elena y TRUJILLO-TOLEDO, Diego Armando

**Editorial label ECORFAN:** 607-8695
**BCIERMMI Control Number:** 2020-04
**BCIERMMI Classification (2020):** 211020-0004

**Pages:** 14
**RNA:** 03-2010-032610115700-14

**ECORFAN-México, S.C.**
143 – 50 Itzopan Street
La Florida, Ecatepec Municipality
Mexico State, 55120 Zipcode
Phone: +52 1 55 6159 2296
Skype: ecorfan-mexico.s.c.
E-mail: contacto@ecorfan.org
Facebook: ECORFAN-México S. C.
Twitter: @EcorfanC

**www.ecorfan.org**

**Holdings**
Mexico Colombia Guatemala
Bolivia Cameroon Democratic
Spain El Salvador Republic
Ecuador Taiwan of Congo
Peru Paraguay Nicaragua

Mechanical Ventilators parameters

Open-source designs shared worldwide

OxyGEN project, Spain

Open Source Ventilator (OSV), Ireland

Project OpenAir, Portugal

RespiraWorks, USA, Guatemala, Kyrgyzstan

The Pandemic Ventilator Project, USA

MIT Emergency Ventilator (E-Vent) Project

Open Source Ventilator Project, University of Florida

Puritan Bennett 560 (PB 560), USA

AmboVent, Israel

Other international efforts

Conclusions

References

# Mechanical Ventilators parameters

The most common commercial modes of mechanical ventilation both provide a specified number of breaths per minute (BPM) and are:

1) synchronized intermittent mandatory ventilation (SIMV) where patients can take additional breadths over the set rate

2) assist control (AC) that uses triggering so that if the patient makes an effort to breathe, it helps them, and if not, it maintains the set rate.

These modes can be used alone or in concert with

1) continuous positive airway pressure (CPAP), which uses a high-pressure reservoir and constant flow of gas that exceeds the patient's needs;

2) positive end-expiratory pressure (PEEP), which increases the residual reserve capacity and allows for many alveoli and small airways to remain open that would otherwise close off;

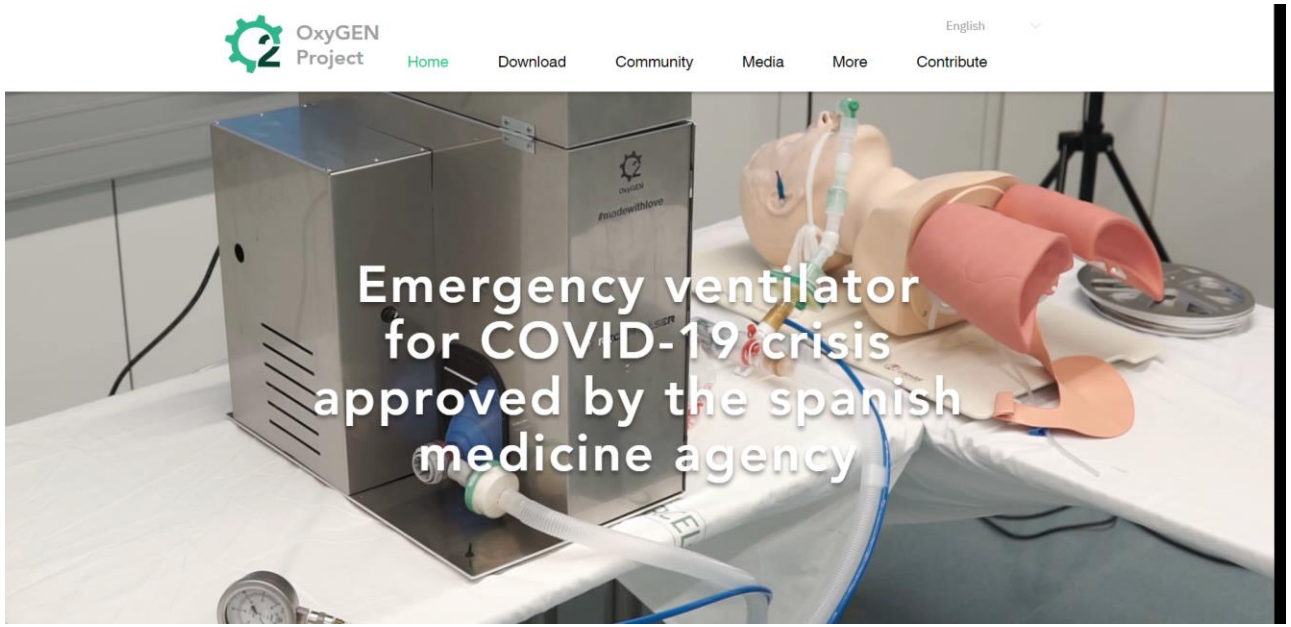
3) pressure support ventilation (PSV), which adjusts the pressure on the fly as the patient breathes to maintain a pre-set inspiratory pressure.

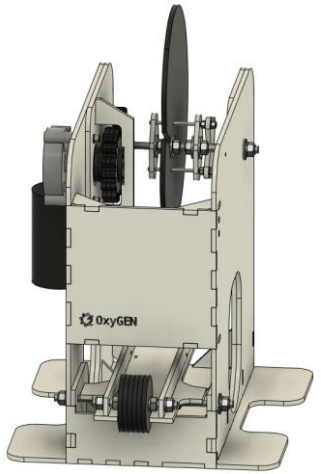
# Open-source designs shared worldwide

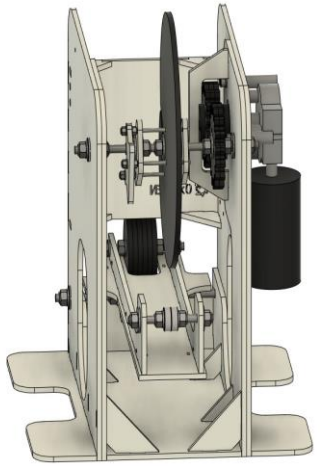
Since the pandemic has affected so many countries, an increase in these types of equipment developed at low cost has been developed these days (Crowell, 2019) (OxyGen Project, 2020).

# OxyGEN project, Spain

- It is a collaborative hardware project initiated and directed by Protofy.xyz, a Spanish company based in Barcelona, in charge of providing innovative hardware and software solutions.
- The project's mission is to provide a chance for survival to those who do not have access to a medical artificial ventilator for any reason.
- It is a low-cost hardware system with simple and easily available components, based on the automation of a manual resuscitator (Ambu-bag), with the idea of contributing to saving lives (OxyGen Project, 2020).
- It has received the approval of the AEMPS (Spanish Agency for Medicines and Health Products) to start its use on patients at all hospitals that adhere to the clinical study.



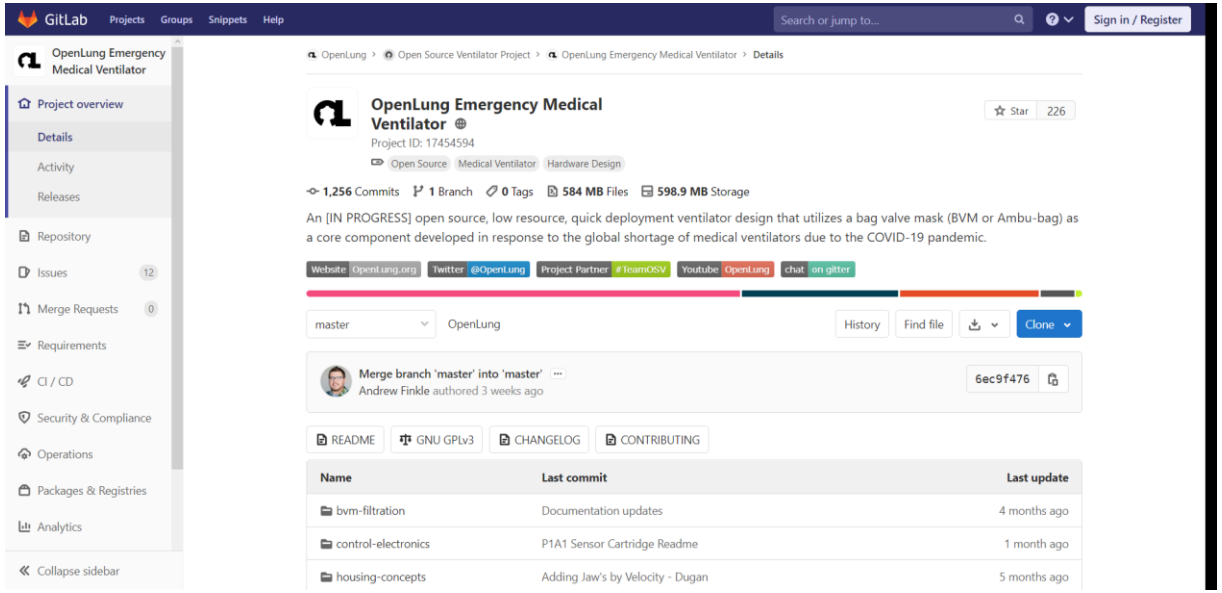



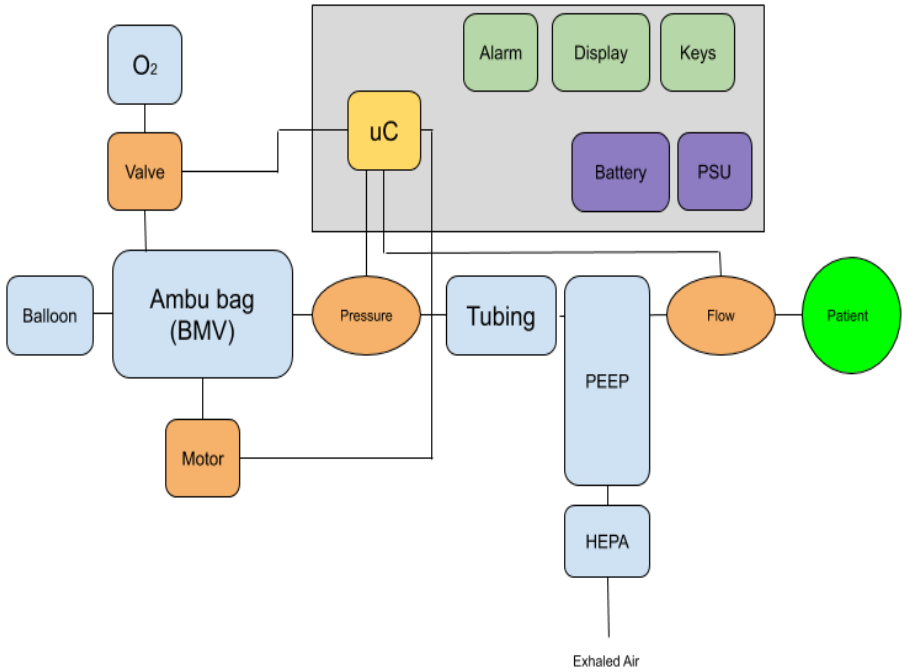



https://www.oxygen.protofy.xyz

# Open Source Ventilator (OSV), Ireland

- The Irish OSV company developed a collaborative Field Emergency Ventilator (FEV) with the Irish Health Service ((OSCMS), 2020).
- They have formed a team of engineers, designers, and medical professionals to develop new low-resource interventions, all working collaboratively online.
- Traditionally manufactured and bagged valve masks (BVMs), 3D printed components are being considered to maximize potential manufacturing capabilities.
- It is a fast-deploying, low-resource, open-source (in progress) fan design that uses a valve bag-mask (BVM or Ambu-bag) as the core component.

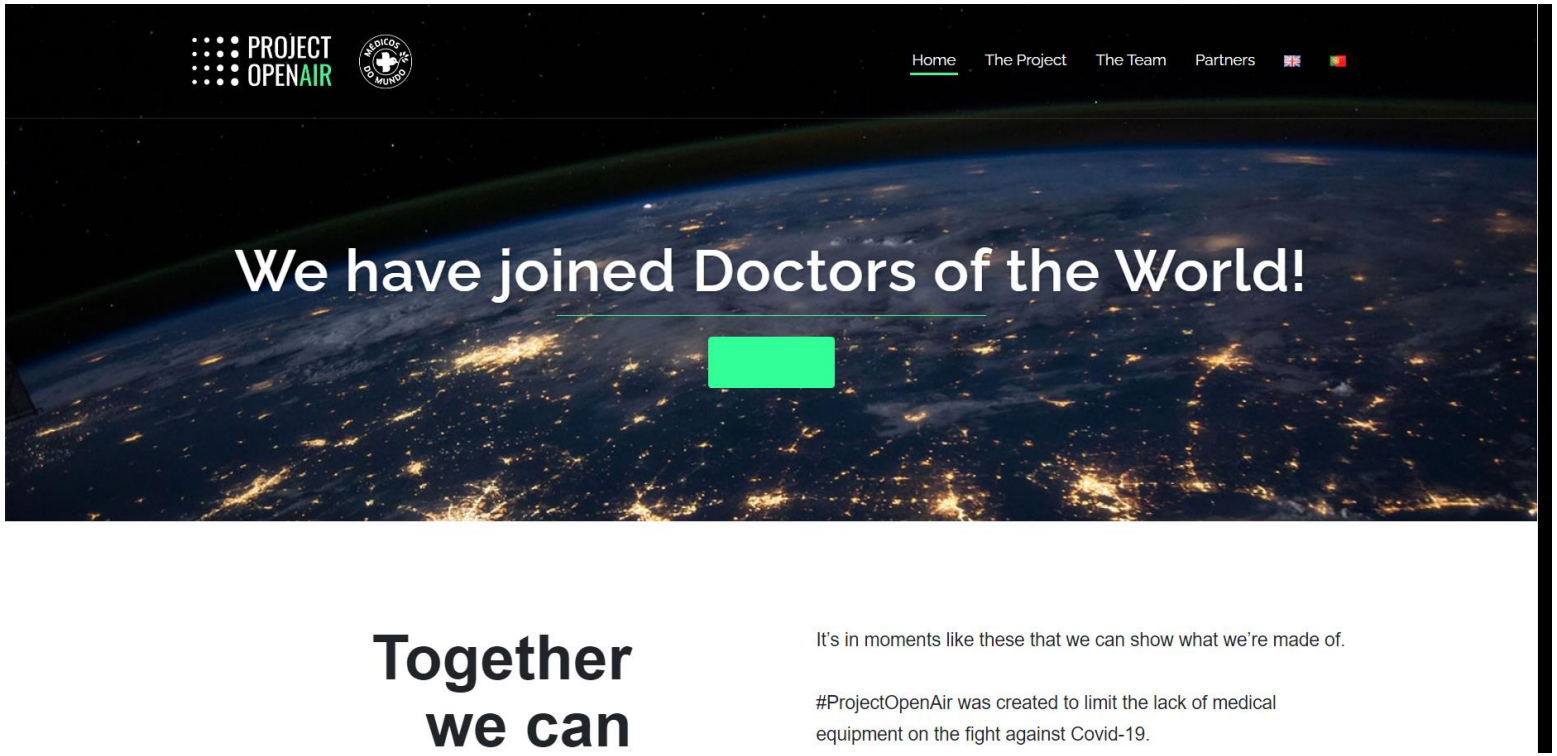



https://gitlab.com/open-source-ventilator/ventilator/OpenLung

# Project OpenAir, Portugal

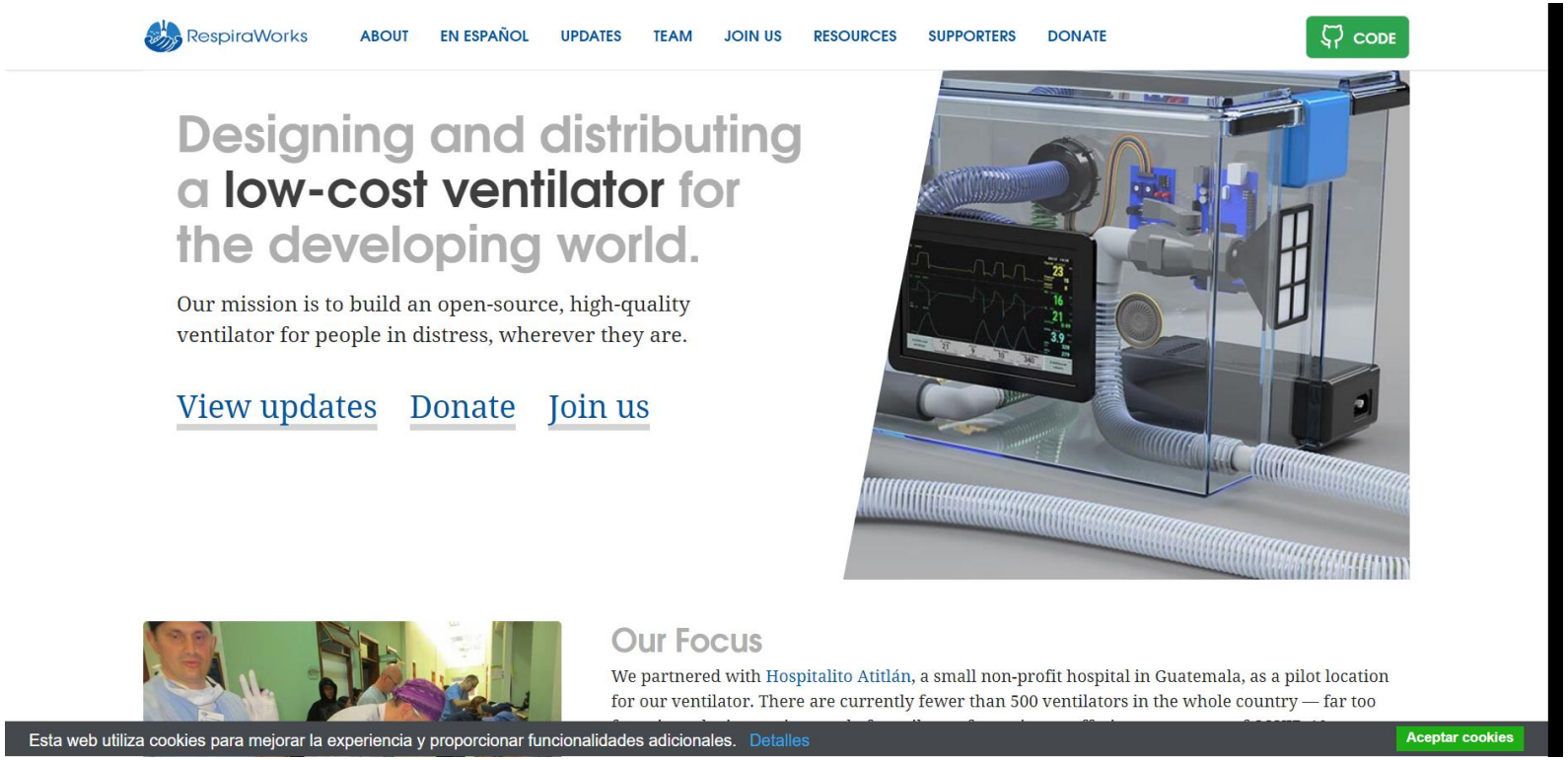
- This prototype implements the pressure-controlled continuous mandatory ventilation mode (PC-CMV) with settable breathing rates, inspiration/expiration time ratios, and FiO2 modulation.
- Pure oxygen at the standard pressure of 4 bar (400 kPa) is fed from the hospital supply to an adjustable pressure regulator with an output range of 20 to 40 mbar, allowing the PIP pressure to be set by just turning a knob.
- The regulator output is fed to the inspiration electro valve that should have enough aperture for the air to pass through easily at normal breathing flows (Pereira et al., 2020a).

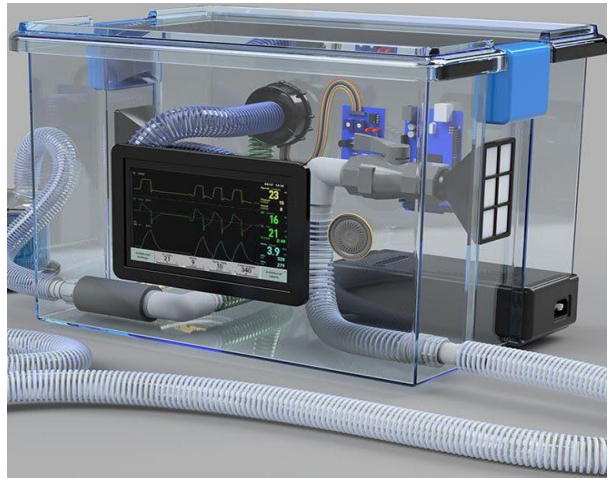


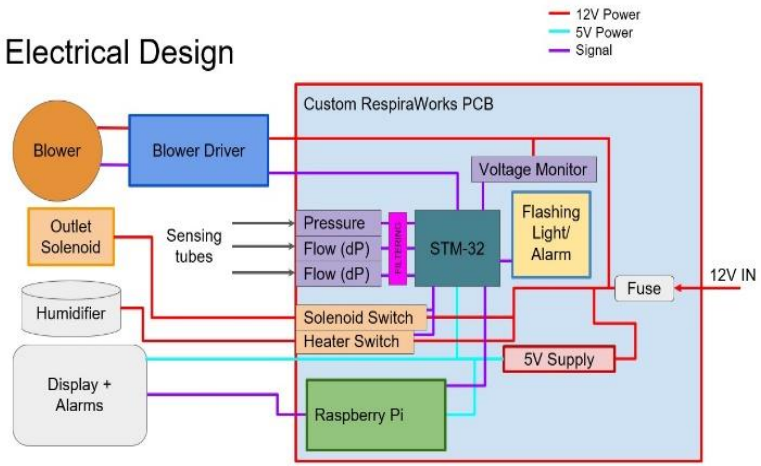

https://projectopenair.org/en/home-2/

# RespiraWorks, USA, Guatemala, Kyrgyzstan

- They are a team with backgrounds in medical devices, quality assurance, nuclear power, submarine life, and project management.
- They are located in Berkeley, Denver, Guatemala, Kyrgyzstan, and places around the world.
- The design of this emergency ventilator is based on a blower



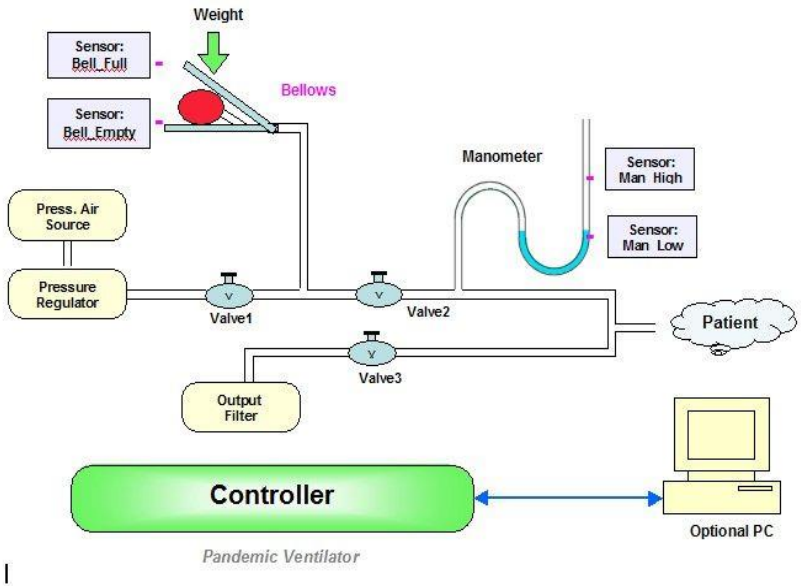



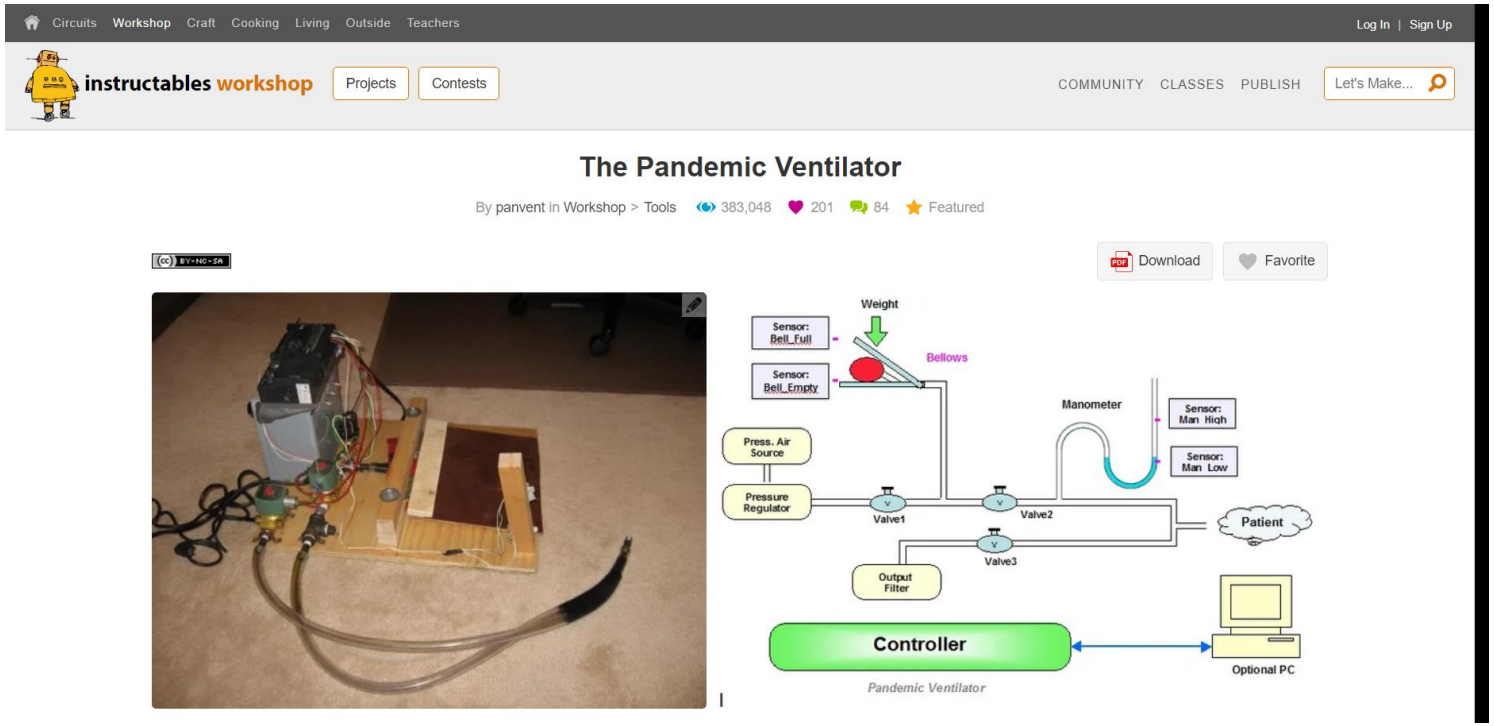



https://respira.works/

# The Pandemic Ventilator Project, USA

- The Pandemic Ventilator Project is an open-source hardware project and the information presented of this project is only for development and investigative purposes.
- The prototypes presented are not fully functional devices and have had no safety testing done.
- This project consists of the bellows unit, which is made of wood, valves and piping, a PLC controller, some wires and switches, and a power supply unit.
- The whole unit is mounted on a piece of 1/2 inch thick plywood that is 18 inches by 21 inches. a device agrees to waive any liability.

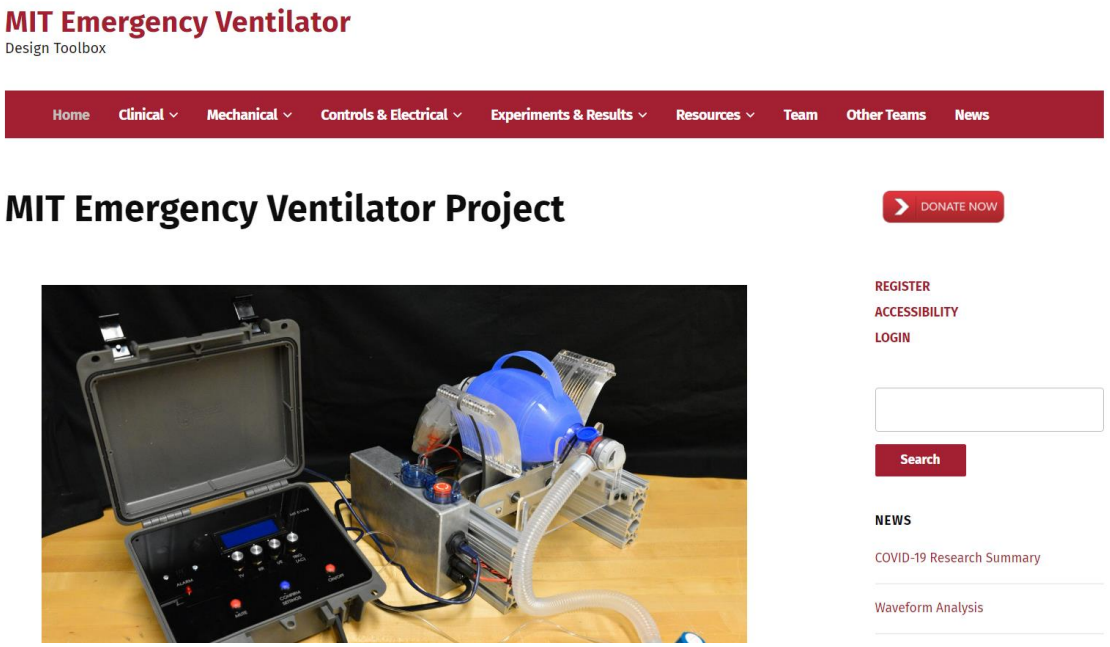


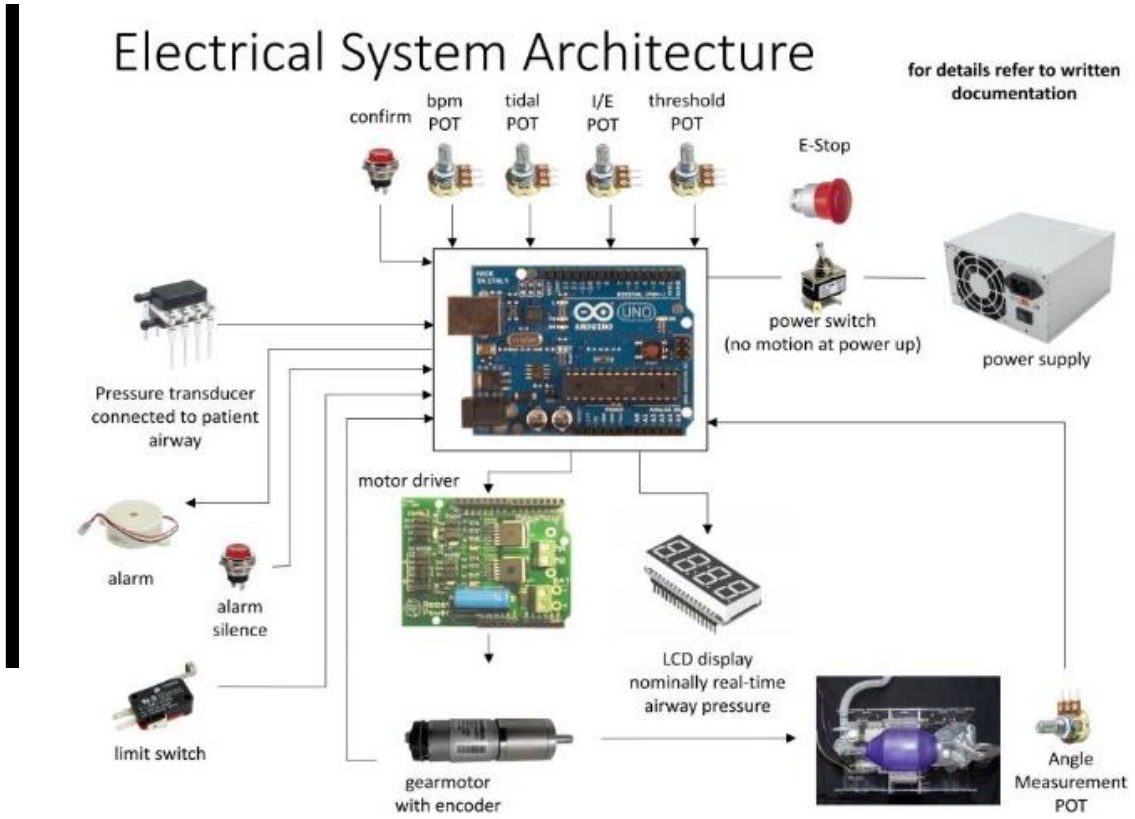




https://www.instructables.com/id/The-Pandemic-Ventilator/

# MIT Emergency Ventilator (E-Vent) Project

- This project is based on automating a manual resuscitator, as a potential means for longer-term ventilation.
- This is a completely off-label use, but they recognize the global interest when a hospital has used up all ventilators and the only option is manual bagging a patient.
- This may allow less severe patients to be cared for by less specialized clinicians, while resources are focused on those most in need. It has a 12V DC @ 5A power supply and is based on the open hardware platform Arduino UNO.

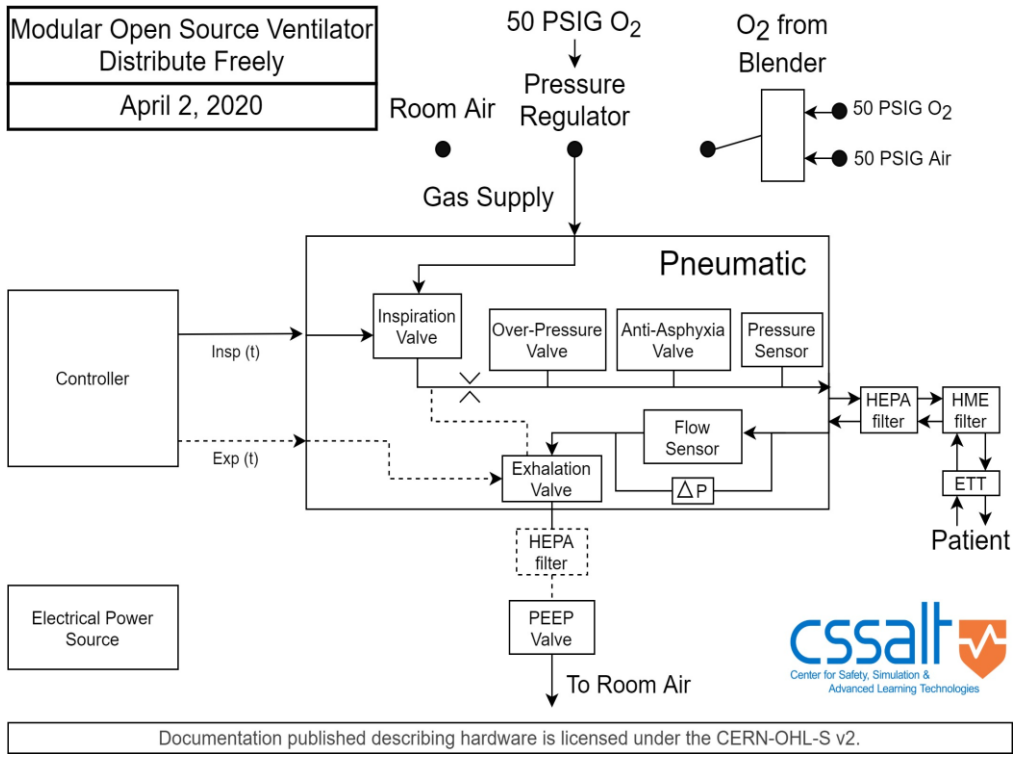


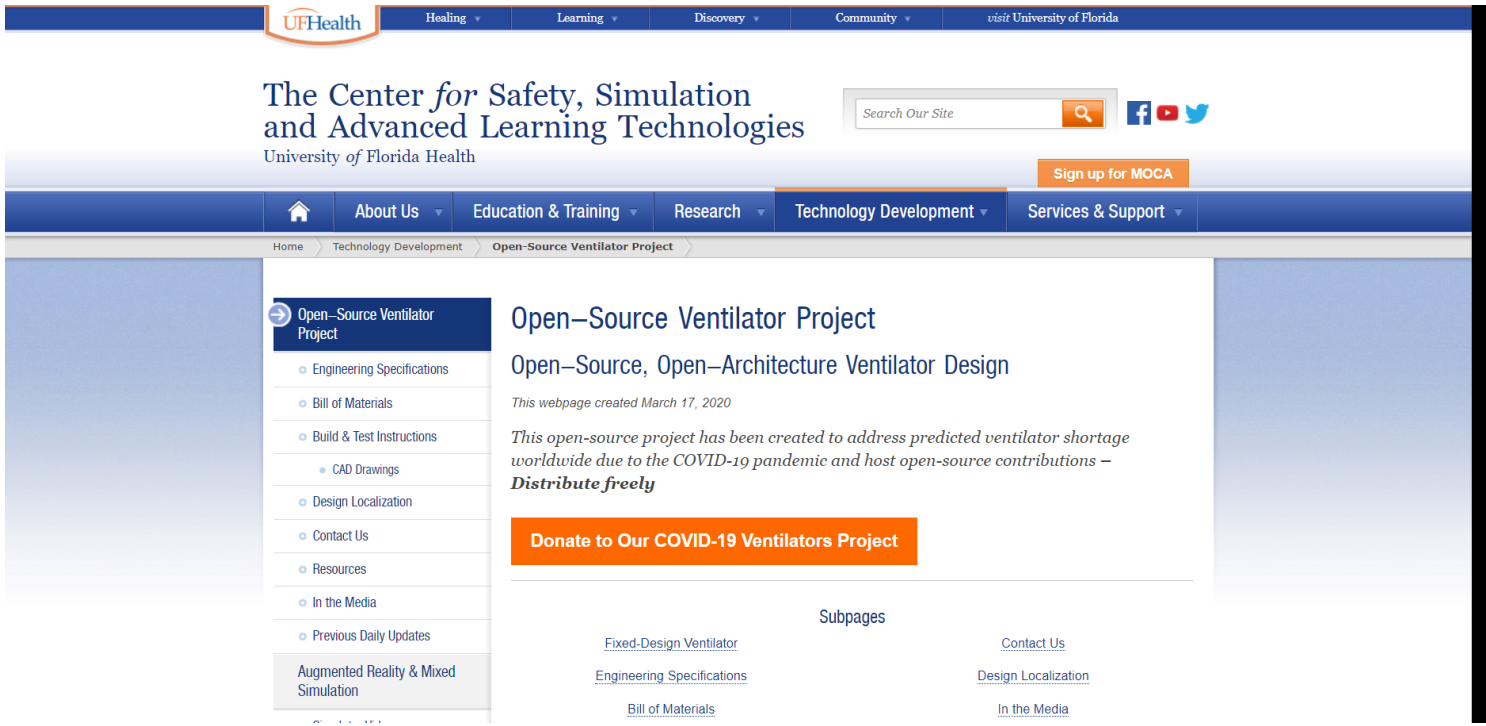




https://e-vent.mit.edu/

# Open Source Ventilator Project, University of Florida

- It is a ventilator system for adults (older adults at higher risk) based on positive pressure-volume control for intubated patients who do not breathe spontaneously.
- The designs are modular, allowing different modules to be combined according to local availability.
- It has an out of box design: all parts are commercially accessible.

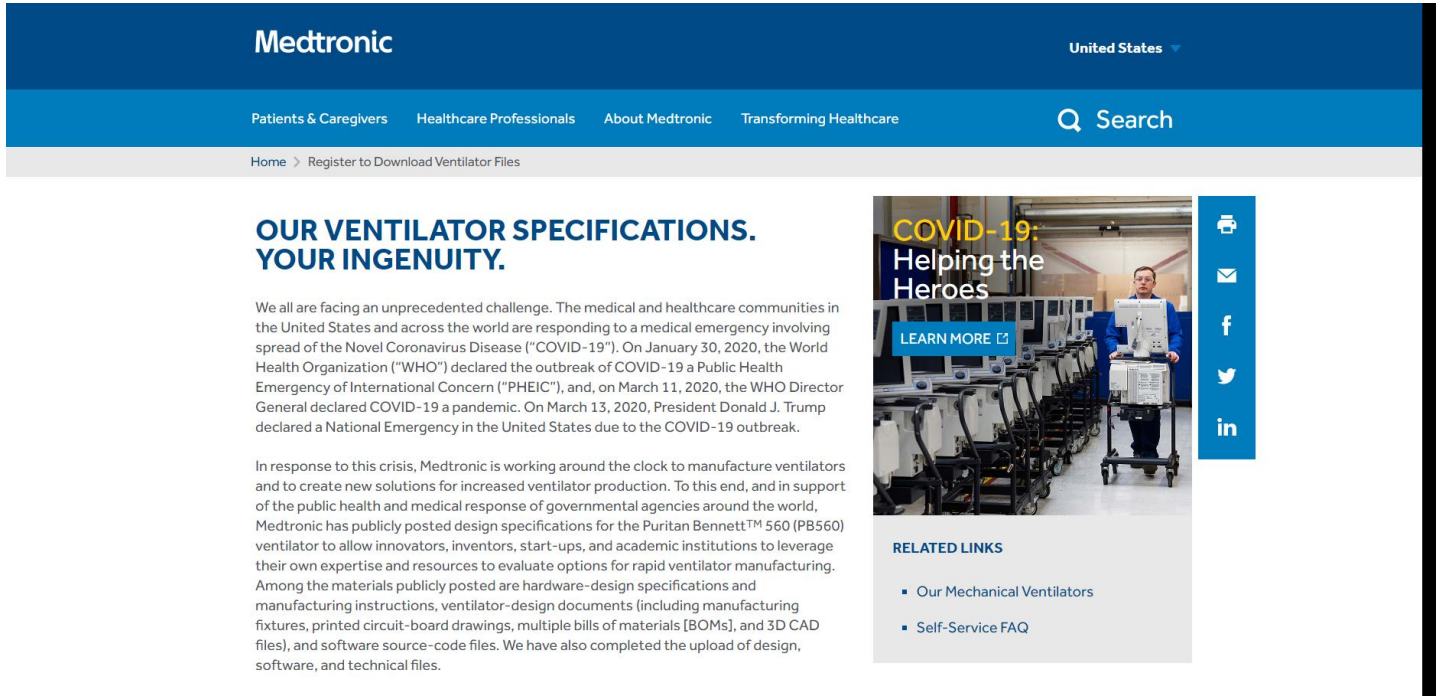



https://simulation.health.ufl.edu/technology-development/open-source-ventilator-project/

# Puritan Bennett 560 (PB 560), USA

- This device plans were released by Medtronic to help people in the COVID 19 pandemic.
- It is pump-based and it was designed in 2010, so it has been a long time in use (Medtronic, 2020).
- This device is more complicated to build and also more expensive, but probably offers more features, and has already been approved by numerous governments.
- Another fact is that some of the elements are discontinued now and it is not easy to find them.
- Also, some industrial facilities are needed to build them.

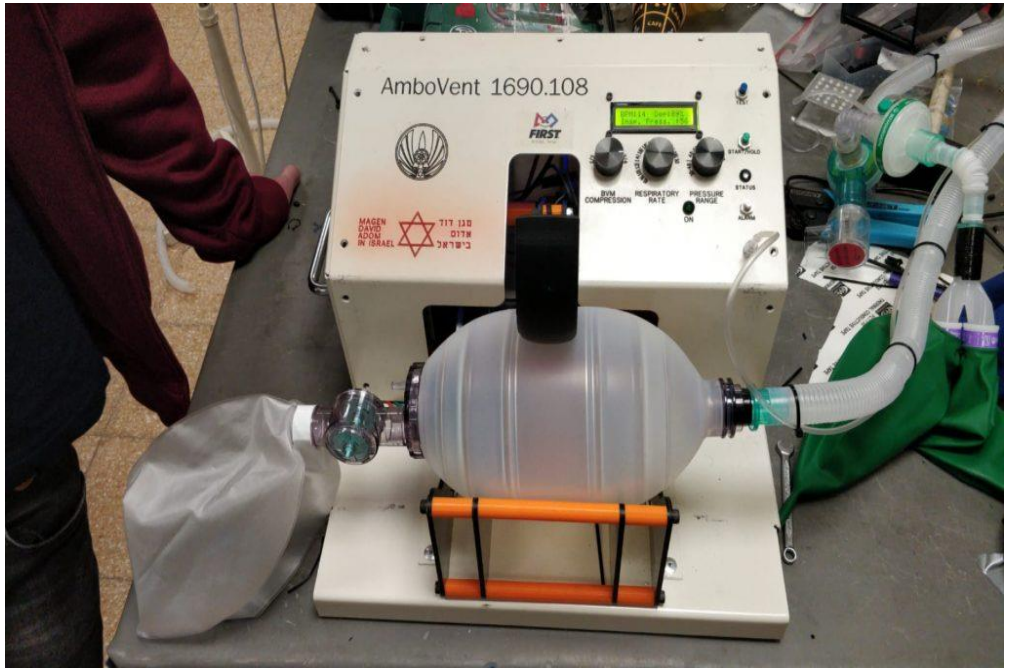




https://www.medtronic.com/us-en/e/open-files.html?cmpid=vanity_url_medtronic_com_openventilator_Corp_US_Covid19_FY20

# AmboVent, Israel

- "AmboVent" is a device inspired by the bag-valve-mask ventilators that paramedics use when they're manually ventilating patients in an ambulance, which also offers controls for respiration rate, volume, and maximum peak pressure.
- The device is being developed as a global partnership for the greater good, in open-source code mentality, on a non-profit basis to enable free and simple mass production by anyone, anywhere in the world.
- It is designed as an alternative automatic, controlled, ventilation system for adults, to be used only in emergencies when no other approved ventilation machines are available (Israel Air Force, 2020).

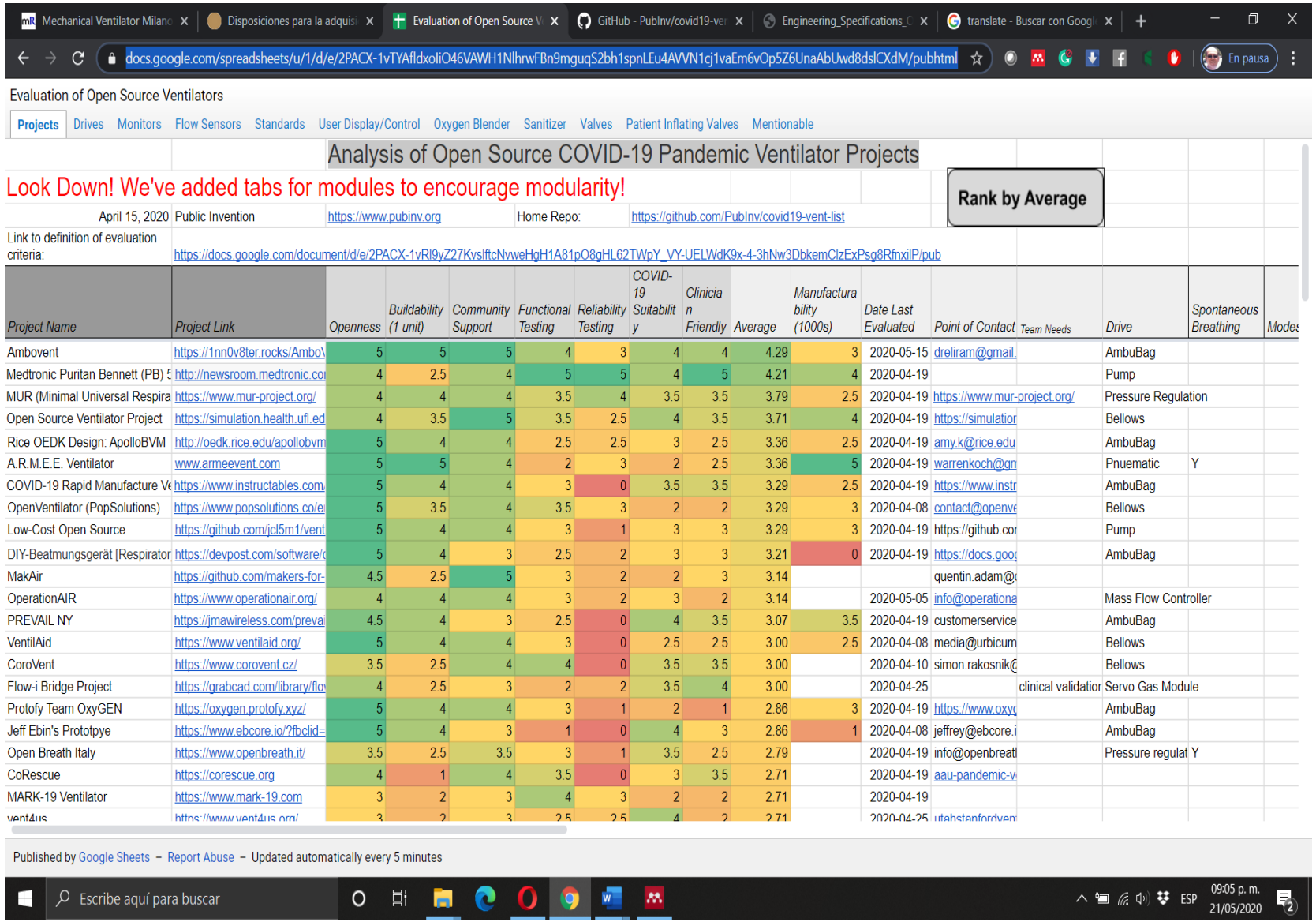




https://members.smoove.io//view.ashx?message=h44741568O122392748O219654O122323322&r=1009

# Other international efforts

At (Read, 2020) is published a classified Analysis of Open Source COVID-19 Pandemic Ventilator Projects



Evaluation of Open Source Ventilators

Projects | Drives | Monitors | Flow Sensors | Standards | User Display/Control | Oxygen Blender | Sanitizer | Valves | Patient Inflating Valves | Mentionable

Analysis of Open Source COVID-19 Pandemic Ventilator Projects

Look Down! We've added tabs for modules to encourage modularity!

Rank by Average

April 15, 2020 Public Invention https://www.pubinv.org Home Repo: https://github.com/PubInv/covid19-vent-list

Link to definition of evaluation criteria: https://docs.google.com/document/d/e/2PACX-1vRl9yZ27KvslftcNvweHgH1A81pO8gHL62TWpY_VY-UELWdK9x-4-3hNw3DbkemClzExPsg8RfnxilP/pub

| Project Name | Project Link | Openness | Buildability (1 unit) | Community Support | Functional Testing | Reliability Testing | COVID-19 Suitability | Clinician Friendly | Average | Manufacturability (1000s) | Date Last Evaluated | Point of Contact | Team Needs | Drive | Spontaneous Breathing | Modes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ambovent | https://1nn0v8ter.rocks/Ambo\ | 5 | 5 | 5 | 4 | 3 | 4 | 4 | 4.29 | 3 | 2020-05-15 | dreliram@gmail. | | AmbuBag | | |
| Medtronic Puritan Bennett (PB) 5 | http://newsroom.medtronic.cor | 4 | 2.5 | 4 | 5 | 5 | 4 | 5 | 4.21 | 4 | 2020-04-19 | | | Pump | | |
| MUR (Minimal Universal Respira | https://www.mur-project.org/ | 4 | 4 | 4 | 3.5 | 4 | 3.5 | 3.5 | 3.79 | 2.5 | 2020-04-19 | https://www.mur-project.org/ | | Pressure Regulation | | |
| Open Source Ventilator Project | https://simulation.health.ufl.ed | 4 | 3.5 | 5 | 3.5 | 2.5 | 4 | 3.5 | 3.71 | 4 | 2020-04-19 | https://simulatior | | Bellows | | |
| Rice OEDK Design: ApolloBVM | http://oedk.rice.edu/apollobvm | 5 | 4 | 4 | 2.5 | 2.5 | 3 | 2.5 | 3.36 | 2.5 | 2020-04-19 | amy.k@rice.edu | | AmbuBag | | |
| A.R.M.E.E. Ventilator | www.armeevent.com | 5 | 5 | 4 | 2 | 3 | 2 | 2.5 | 3.36 | 5 | 2020-04-19 | warrenkoch@gn | | Pnuematic | Y | |
| COVID-19 Rapid Manufacture Ve | https://www.instructables.com/ | 5 | 4 | 4 | 3 | 0 | 3.5 | 3.5 | 3.29 | 2.5 | 2020-04-19 | https://www.instr | | AmbuBag | | |
| OpenVentilator (PopSolutions) | https://www.popsolutions.co/e | 5 | 3.5 | 4 | 3.5 | 3 | 2 | 2 | 3.29 | 3 | 2020-04-08 | contact@openve | | Bellows | | |
| Low-Cost Open Source | https://github.com/jcl5m1/vent | 5 | 4 | 4 | 3 | 1 | 3 | 3 | 3.29 | 3 | 2020-04-19 | https://github.cor | | Pump | | |
| DIY-Beatmungsgerät [Respirator | https://devpost.com/software/c | 5 | 4 | 3 | 2.5 | 2 | 3 | 3 | 3.21 | 0 | 2020-04-19 | https://docs.goo | | AmbuBag | | |
| MakAir | https://github.com/makers-for- | 4.5 | 2.5 | 5 | 3 | 2 | 2 | 3 | 3.14 | | | quentin.adam@ | | | | |
| OperationAIR | https://www.operationair.org/ | 4 | 4 | 4 | 3 | 2 | 3 | 2 | 3.14 | | 2020-05-05 | info@operationa | | Mass Flow Controller | | |
| PREVAIL NY | https://jmawireless.com/preva | 4.5 | 4 | 3 | 2.5 | 0 | 4 | 3.5 | 3.07 | 3.5 | 2020-04-19 | customerservice | | AmbuBag | | |
| VentilAid | https://www.ventilaid.org/ | 5 | 4 | 4 | 3 | 0 | 2.5 | 2.5 | 3.00 | 2.5 | 2020-04-08 | media@urbicum | | Bellows | | |
| CoroVent | https://www.corovent.cz/ | 3.5 | 2.5 | 4 | 4 | 0 | 3.5 | 3.5 | 3.00 | | 2020-04-10 | simon.rakosnik@ | | Bellows | | |
| Flow-i Bridge Project | https://grabcad.com/library/flo | 4 | 2.5 | 3 | 2 | 2 | 3.5 | 4 | 3.00 | | 2020-04-25 | | clinical validatior | Servo Gas Module | | |
| Protofy Team OxyGEN | https://oxygen.protofy.xyz/ | 5 | 4 | 4 | 3 | 1 | 2 | 1 | 2.86 | 3 | 2020-04-19 | https://www.oxyg | | AmbuBag | | |
| Jeff Ebin's Prototpye | https://www.ebcore.io/?fbclid= | 5 | 4 | 3 | 1 | 0 | 4 | 3 | 2.86 | 1 | 2020-04-08 | jeffrey@ebcore.i | | AmbuBag | | |
| Open Breath Italy | https://www.openbreath.it/ | 3.5 | 2.5 | 3.5 | 3 | 1 | 3.5 | 2.5 | 2.79 | | 2020-04-19 | info@openbreatl | | Pressure regulat | Y | |
| CoRescue | https://corescue.org | 4 | 1 | 4 | 3.5 | 0 | 3 | 3.5 | 2.71 | | 2020-04-19 | aau-pandemic-v | | | | |
| MARK-19 Ventilator | https://www.mark-19.com | 3 | 2 | 3 | 4 | 3 | 2 | 2 | 2.71 | | 2020-04-19 | | | | | |
| vent4us | https://www.vent4us.org/ | 3 | 2 | 3 | 2.5 | 2.5 | 4 | 2 | 2.71 | | 2020-04-25 | utahstanfordven | | | | |

Published by Google Sheets – Report Abuse – Updated automatically every 5 minutes

The ventilation projects are qualified from 0 or 1 to 5, in seven categories:

- Openness,
- Community Support,
- Buildability,
- Functionally Tested,
- Reliability Tested,
- COVID-19 Suitability,
- Clinician Friendly.

https://docs.google.com/spreadsheets/d/1inYw5H4RiL0AC_J9vPWzJxXCdlkMLPBRdPgEVKF8DZw/edit#gid=0

# Conclusions

- There are a lot of different projects for designing and replicating ventilators for people in this COVID 19 pandemic.
- We can conclude that most of the projects developed worldwide are not approved yet for medical use, except for the OxyGen Project and the Medtronic's Puritan Bennett 560, but the buildability parameter is very important.
- The information collected and classified in the Analysis of Open Source COVID-19 Pandemic Ventilator Projects is very useful to know the international experiences obtained in the design and construction of these ventilators.
- Also, there are different kinds of ventilators, so anyone can choose the one who fits the needs of their local community.

| Project | Country | Drive | Build | Average | |
|---|---|---|---|---|---|
| OxyGEN | Spain | Ambu bag | 4 | 2.95 | 4 |
| OSV | Ireland | Ambu bag | 2 | 0.90 | |
| Open Air | Portugal | Pressure Control | 1 | 0.70 | |
| Respira Works | USA-Guatemala | Fan | 4 | 3.25 | 2 |
| Pandemic Ventilator | USA | Bellow | 1 | 1.30 | |
| E-Vent | USA | Ambu bag | 3 | 2.80 | |
| Open Source Ventilator | USA | Positive Pressure Control | 3.5 | 3.15 | 3 |
| Puritan Bennett 560 | USA | Pump | 2.5 | 4.45 | 1 |
| AmboVent | Israel | Ambu bag | 5 | 4.45 | |

# References


- (OSCMS), O. S. C.-19 M. S. (2020). Open Source Ventilator. Retrieved May 13, 2020, from https://opensourceventilator.ie/
- Andreoli, T., Benjamin, I. J., Grigss, R. C., & Wing, E. J. (2015). Cecil Essentials of MEDICINE. In Saunders, Elsevier (Vol. 6). https://doi.org/10.1017/CBO9781107415324.004
- Crowell, R. (2019). Conoce el respirador manual automatizado que estamos creando en la UFG - Revista Disruptiva. Retrieved April 20, 2020, from Investigación y Ciencia website: https://www.disruptiva.media/conoce-el-respirador-manual-automatizado-que-estamos-creando-en-la-ufg/
- Florida, U. (2020). Open Source Ventilator Project » The Center for Safety, Simulation and Advanced Learning Technologies » UF Academic Health Center » University of Florida. Retrieved May 21, 2020, from https://simulation.health.ufl.edu/technology-development/open-source-ventilator-project/
- Force, I. A. (2020). Welcome to AmboVent 1690.108. Retrieved May 22, 2020, from https://members.smoove.io//view.ashx?message=h44741568O122392748O219654O122323322&r=1009
- Gobierno de México. (2020). Instituto de Salud para el Bienestar | Instituto de Salud para el Bienestar | Gobierno | gob.mx. In Blog Instituto de Salud para el Bienestar. Retrieved from https://www.gob.mx/insabi/articulos/instituto-de-salud-para-el-bienestar-230778
- Instructables. (2020). The Pandemic Ventilator : 6 Steps (with Pictures) - Instructables. Retrieved May 18, 2020, from https://www.instructables.com/id/The-Pandemic-Ventilator/
- Medtronic. (2020). Register to Download Ventilator Files | Medtronic. Retrieved May 22, 2020, from https://www.medtronic.com/us-en/e/open-files.html?cmpid=vanity_url_medtronic_com_openventilator_Corp_US_Covid19_FY20
- MIT, T. (2020). MIT E-VENT | Emergency ventilator design toolbox. Retrieved May 18, 2020, from https://e-vent.mit.edu/
- OxyGen PRoject. (2020). OxyGEN Project. Retrieved April 20, 2020, from https://www.oxygen.protofy.xyz/
- Pearce, J. M. (2020a). A review of open source ventilators for COVID-19 and future pandemics. F1000Research, 9, 218. https://doi.org/10.12688/f1000research.22942.1
- Pearce, J. M. (2020b). A review of open source ventilators for COVID-19 and future pandemics. F1000Research, 9, 218. https://doi.org/10.12688/f1000research.22942.1
- Pereira, A., Lopes, L., Fonte, P., Póvoa, P., Santos, T. G., Martinho, A., … Pimenta, M. (2020). Prototype of an affordable pressure-controlled emergency mechanical ventilator for COVID-19.
- Read, R. L. (2020). Analysis of Open Source COVID-19 Pandemic Ventilator Projects. Retrieved May 23, 2020, from https://medium.com/@RobertLeeRead/analysis-of-open-source-covid-19-pandemic-ventilator-projects-27acf9075f7e
- RespiraWorks, T. (2020). Home | RespiraWorks. Retrieved May 14, 2020, from https://respira.works/
- Secretaría de Salud, G. de M. (2020). COVID-19 - gob.mx. Retrieved April 20, 2020, from https://coronavirus.gob.mx/covid-19/
- Sloan, M. (2020). MDA and other Israeli organizations partner on making low-cost ventilator for coronavirus | AFMDA | Saving Lives in Israel. Retrieved May 22, 2020, from https://afmda.org/low-cost-ventilator-for-coronavirus/
- Williams, M. (Rice U. (2019). Student invention gives patients the breath of life. Retrieved April 20, 2020, from Rice News website: http://news.rice.edu/2019/05/01/student-invention-gives-patients-the-breath-of-life-2/
- Worldometer. (2020). Coronavirus Cases. https://doi.org/10.1101/2020.01.23.20018549V2

ECORFAN®