**This document was prepared following** [**user need requirements**](https://drive.google.com/file/d/1WitcPoqPPmHopEo9YMWe8MoB9p_oZJxK/view?usp=sharing)**, collected from Ethiopian medical doctors and clinicians,** [**MIT E-Vent Design Toolbox**](https://e-vent.mit.edu/) **AND rapidly manufactured ventilator system** [**document specification**](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/879382/RMVS001_v4.pdf) **issued by MHRA, UK government. We are proposing a** [**design and development plan**](https://drive.google.com/file/d/1XvoGB-r7dA24zw7E4kKBlHemAfWygtyN/view?usp=sharing) **following ISO 13485 design controls and ISO 14971 risk management standards.**

**Introduction**

The impending effects of the spread of the novel coronavirus disease (COVID-19) and the current state of resources in Ethiopia are a major source of concern to the Ethiopian population. In the specific case of ventilators, which serve a crucial purpose in rehabilitating individuals significantly affected by the disease, most if not all the equipment have been previously imported into the country; and, the country still faces a significant shortage of these devices. Recently, due to the COVID-19 pandemic caused by the SARS-COV-2 virus, the need to manufacture these ventilators locally in Ethiopia has become widely apparent.

This is a specification of the minimal clinically accepted ventilator to be used in Ethiopian hospitals during this pandemic. It sets out the clinical requirements based on the consensus of what is ‘minimally acceptable’ performance in the opinion of UK medical device regulators (MHRA), MIT E-Vent Design Toolbox and Ethiopia’s intensive care medicine professionals involved in the initial care of patients requiring urgent ventilation. A ventilator with lower specifications than this is likely to provide no clinical benefit and might lead to increased harm, which would be unacceptable for clinicians.

Please note, intensive care medicine is a whole system of care and ventilators cannot be safely used on any patient without trained staff and other equipment and medicines.

It is proposed these ventilators would be for short-term stabilization for a few hours, but this may be extended up to 24 hours of use for a patient in extremis as the bare minimum function.

**Key specifications**

**Clinical**

1. Patients must be under management of a trained clinician for mandatory ventilation.

The minimum controllable parameters in order to ventilate are as follows:

* At least 1, optionally 2 modes of ventilation listed below must be included.
* Mandatory mode must be either: **Pressure Regulated Volume Control (PRVC)**, **pressure-controlled ventilation (PCV),** or **volume-controlled ventilation (VCV)**

a. **PRVC/Pressure Controlled** - a set pressure is delivered for the period of inspiration and the volume achieved is measured and displayed. Ideally PRVC, an adaptive mode where the tidal volume is set and the lowest possible pressure is delivered to achieve this volume. Pressure Control Ventilation where the user has to provide the adaptive control to achieve tidal volume is only acceptable if the tidal volume delivered is clearly displayed and the user can set patient specific upper and lower tidal volume alarms to alert to the need to adjust the pressure.

b. **Volume Control** – the user sets a tidal volume and respiratory rate. The tidal volume is delivered during the inspiratory period. Acceptable only if additional pressure limiting controls are available, see *Inspiratory airway pressure* section.

c. Optional pressure support mode for those patients breathing to some extent themselves, e.g. BIPAP or SIMV-PC. The user sets an inspiratory pressure and an expiratory pressure. The ventilator can sense when a patient starts to breathe in and apply the inspiratory pressure, then sense when the patient starts to breathe out and apply the expiratory pressure (this pressure is still positive but lower than the inspiratory pressure).

2. If the patient stops breathing in a spontaneous mode it must failsafe automatically onto mandatory ventilation.

3. **Inspiratory airway pressure, the higher pressure setting that is applied to make the patient breathe in:**

a. **Plateau pressure** should be adjusted to achieve volume and be limited to 35 cmH2O by default. It is acceptable if an option to increase this to 70 cmH2O in exceptional circumstances is provided

b. **Peak pressure** should be no more than 2 cmH2O greater than plateau pressure.

c. If volume control ventilation is used, the user must be able to set the **inspiratory airway pressure** limit in the range at least 15 – 40 cmH2O in at least increments of 5 cmH2O.

d. There must be a mechanical failsafe valve that opens at 80 cmH2O.

4. **Positive End Expiratory Pressure (PEEP).** The pressure maintained in the breathing system during expiration.

a. Airway pressure must be monitored: Range 5-20 cmH2O adjustable in 5 cmH2O increments required. Many patients need 10–15 cmH2O.

b. Assist Detection pressure or Trigger Sensitivity: When a patient tries to inspire, they can cause a dip on the order of 1 to 5 cmH2O, with respect to PEEP pressure (not necessarily equal to atmospheric pressure).

c. Patient breathing system must remain pressurized to at least the PEEP

level setting at all times.

5. **Inspiratory: Expiratory ratio (I:E).** The proportion of each breathing cycle that is spent breathing in compared to breathing out.

a. 1:2.0 (i.e. expiration lasts twice as long as inspiration).

b. Optionally adjustable in the range 1:1 – 1:3.

6. **Respiratory Rate.** The number of breathing cycles every minute.

a. Range 10 – 30 breaths per minute in increments of 2 (only in mandatory

mode) can be set by the user.

7. **Tidal Volume (Vt) setting, if provided**. The volume of gas flowing into the lungs during one inspiratory cycle

a. Must have at least one setting of 400ml +/- 10 ml.

b. Ideally 350 ml and 450 ml options.

c. Optionally Range 250 – 600 ml in steps of 50 ml.

d. Even more optionally up to 800 ml.

e. Optionally the ability to input body weight and have volume calculated as e.g. 6 ml/kg of ideal body weight.

8. Failure conditions must permit conversion to **manual clinician override**, i.e. if automatic ventilation fails, the conversion to immediate ventilation must be immediate.

9. Ventilation of r**oom air is better than no ventilation at all**. Blending of oxygen and air gas mixture to adjust FiO2 is not important in an emergency scenario. It is certainly nice to have that ability and can easily be implemented with an oxygen/air gas blender that some hospitals already have.

10. COVID-19 can get aerosolized (airborne), so **HEPA filtration** **on the patient’s exhalation** **is required or between the ventilator unit and the patient (at the end of the endotracheal tube)** to protect clinical staff from certain infections. In-line HEPA filters can usually be purchased alongside manual resuscitator bags.

11. Heat and moisture exchanger should be used in line with the breathing circuit. Failure conditions must result in an alarm. This is a minimum requirement set for emergency use. Equipment designed for more regular use, even if for emerging markets, will require additional features to be used on a regular basis.

12. Any ventilator design must incorporate pressure sensing and actively monitor both peak and plateau pressures.

13. Peak pressure exceeding 40 cmH2O (or a pressure set just below the pop-off pressure of the selected bag) must trigger an alarm.

**Gas and electricity**

**1. Incoming Gas Supply**

a. All gas connectors and hoses must comply with BS EN ISO 5359:2014+A1:2017, ISO 5359:2014/AMD 1:2017 and BS 2050: 1978 Electrical Conductivity.

b. Must connect to wall pipeline oxygen supply via BS 5682:2015 compatible probes (Schrader). If the hose is not permanently fixed to the machine, then it must connect with NIST (Non-Interchangeable Screw Thread to ISO 18082:2014/AMD 1:2017). Oxygen pipeline pressure is approximately 3.7 – 4.5 bar.

c. Oxygen supply from wall outlets outside of ICU and theatres is limited to approximately 6-10 lpm (HTM\_02-01\_Part\_A) and so provision for a gas reservoir will be required to manage peak inspiratory flow rates of up to 100 lpm

d. Average oxygen consumption must be no more than 3 lpm. This may be allowed to increase as greater certainty is gained over oxygen supply.

e. Optionally can connect to wall pipeline Medical Air (MA4, NOT SA7) via BS 5682:2015 compatible probes.

f. Optionally can connect to ISO 7396-2:2007 compatible Anaesthetic Gas Scavenging System or an external activated charcoal absorber (If inhaled anaesthetic agents are being used).

g. If oxygen outlets are not expected, it can optionally operate using an oxygen concentrator device for input oxygen, these will typically be limited to 10 lpm.

**2. Gas supply to Patient**

a. Users must be able to control inspired oxygen proportion (FiO2). The percentage of oxygen in the gas being breathed in by the patient. Room air is 21% oxygen.

b. At least 50% (or 60%) and 100% options

c. Ideally variable between 30 – 100 % in 10% steps.

d. Patient breathing system connections: the ventilator must present 22mm outside diameter (OD) ‘male’ standard connectors to ISO 5356-1:2015 on both outlet and inlet ports for connection to user supplied 22mm ‘female’ connectors on the breathing system. These must be rigid and robust (not plastic) and separated by a minimum of 10 cm between centres to accommodate filter HMEs.

All elements in the gas pathway must meet biological safety and low-pressure oxygen safety standards, especially to minimize risk of fire or contamination of the patient’s airway.

**3. Electricity Supply**

a. Should connect to 220-240V main supply. This will avoid electrical components designed for 60 HZ System with additional backup generator supply.

b. Should be PAT tested to the adapted IEC 60601, IEC 62353 standards. There are normally required standards to verify emissions and immunity to electromagnetic disturbances.

c. Battery backup – Must have a minimum of 20 minutes back up battery in case of mains electricity failure.

d. Optionally hot swappable batteries so that it can be run on battery supply for an extended period, e.g. 2 hours for within hospital transfer. This is a good option to consider in design as power failure is expected in Ethiopia.

e. Must avoid harmful RF or EM emissions that could interfere with other critical machinery.

f. The minimum motor power is approximately 70 W. Therefore, a power supply at 12 V should be specified with a minimum of a 5.8 (~6 A) supply.

**Infection control**

1. All parts coming into contact with the patient’s breath must be either disposable or able to be decontaminated between patients.

2. All external surfaces must be cleanable in the likely event that they get respiratory secretions or blood splatter on them. Cleaning would be by healthcare workers manually wiping using an approved surface wipe with disinfectant or cloths and approved surface cleaning liquid.

3. There will be a separately sourced HMEF-bacterial-viral filter between the machine and patient which may impact on resistance within the system, which may need to be accounted for with some designs. The pressure being delivered to the patient is the specified pressure. If the filter has a resistance of, say 2 cmH2O at 30 lpm, the ventilator needs to output 37 cmH2O to achieve a set 35 cmH2O at the patient. This will need further detailed consideration. Viral filtering filters may have much higher resistance that may be clinically relevant.

4. Optionally include a facility for hot water humidifiers to be included in the breathing system.

**Monitoring and Alarms**

1. Must alarm at minimum:

a. Gas or electricity supply failure.

b. Low Battery level (when operating on battery mode)

b. Machine switched off while in mandatory ventilation mode.

c. Inspiratory airway pressure exceeded.

d. Inspiratory and PEEP pressure not achieved (equivalent to disconnection alarm).

e. Tidal volume not achieved or exceeded.

2. Monitoring – the following should be continuously displayed so the user can verify.

a. Current settings of tidal volume, frequency, PEEP, FiO2, ventilation mode.

b. Actual achieved rates of tidal volume, breathing rate, PEEP, plateau pressure, FiO2.

c. If it exists, in pressure support mode there must be real time confirmation of each patient's breath and an alarm if below acceptable range.

d. Optionally CO2 monitoring included.

**Miscellaneous**

1. Must be reliable. It must have a 100% duty cycle for up to 14 days.

2. Optionally, it can be used beyond 14 days. The expected durability must be specified.

3. Can be floor standing or portable.

4. Ideally small and light enough to mount on a patient bed and orientation independent functioning.

5. Should be as robust as possible. For example, it may be dropped from bed height to floor.

6. It must be intuitive to use for qualified medical personnel, but these may not be specialists in ventilator use.

a. Must not require more than 30 minutes training for a doctor with some experience of ventilator use.

b. Must include Instructions for Use.

c. Ideally instructions for use should be built into the labelling of the ventilator, e.g. with ‘connect this to wall’ etc.

d. Must include clear labelling of all critical functions and controls using standard terms, pictograms and colors that will be readily recognized by Ethiopian healthcare staff.

7. Must have transparent design, supply chain, manufacture, quality assurance and testing processes that are of sufficient quality following ISO 13485 and ISO14971 to enable Ethiopia FDA officials to deem appropriate for usage in exceptional circumstances.

8. Must not be excessively cumbersome so that it would impede hospital operations or prevent easy movement within hospital premises.

9. Must be made from materials and parts readily available in Ethiopia supply chain (anticipating increasing global restrictions on freight movement).

10. Relevant Standards – Advisory and applicable to ventilators.

a. BS EN 794-3:1998 +A2:2009 Particular requirements for emergency and transport ventilators

b. ISO 10651-3:1997 Lung Ventilators for Medical Use - Emergency and Transport

c. BS ISO 80601-2-84:2018 Medical electrical equipment. Part 2-84. Particular requirements for basic safety and essential performance of emergency and transport ventilators – especially the parts on ‘patient gas pathway’ safety (very similar to IEC 60601)

d. ISO 80601-2-12:2020 Medical electrical equipment — Part 2-12: Particular requirements for basic safety and essential performance of critical care ventilators

e. BS ISO 19223:2019 Lung ventilators and related equipment. Vocabulary and semantics

**Testing**

1. It is accepted that full demonstration of compliance to [**ISO 80601-2-12:2020**](https://drive.google.com/open?id=17LxYLbfzzse89G70xYauKqdOjAa3BnZ5) is unrealistic in the time frame required for development. Nevertheless, compliance with the essential safety standards must be demonstrated for patient safety.

2. It is not anticipated that the device will gain 510(k) clearance from the U.S FDA or CE market given the time constraint due to pandemic. Therefore, we are proposing approval from Ethiopia FDA following the “Exceptional use of non-CE marked medical devices” route.

Manufacturer/Applicant is required to present the following:

a. Identify predicate devices (similar devices currently in use)

b. Clinical investigations currently using device

c. Details of aspects of device that differentiate it from other devices already on the market

d. Information on risk analysis, identification of hazards, estimation of risks and how such risks have been addressed, together with information to support a positive risk benefit analysis

3. Applicants will derive a Usability testing plan leveraging [Formative Usability Test released by UK Gov](https://drive.google.com/file/d/1ClyIX4NcIDQ8isVjATpTJsIAS02Tm5z2/view?usp=sharing) at both **prototype** and **final production** stages will be required. This should be done as a short Formative Usability Test to ISO 62366 in a realistic environment .The user will be wearing complex protective clothing which includes: Eye goggles (in addition to spectacles if worn), Face shield, Plastic apron, Surgical gown, Two layers of gloves, usually nitrile non- handed small, medium, large variants, Gloves are donned in layers and sticky taped onto sleeves of gown in between layers

4. The user must be able to instantly see the settings selected and be able to easily operate all controls while dressed in protective gear. They may be required to remain so clothed and operate the ventilator for a number of hours without breaks.

**Glossary**

BIPAP – Bilevel Positive Airway Pressure: a non-invasive ventilation mode that provides different levels of pressure when the patient inhales and exhales.

EM – ElectroMagnetic Emissions: Many medical devices are sensitive to EM interference. Care should be taken to ensure that this is kept to a minimum.

FiO2 – Fraction of inspired oxygen: concentration of oxygen in the gas mixture that the patient inhales

HMEF – Heat and Moisture Exchange Filter: device fitted to the patient end of the breathing system, contains a hydrophobic medium that absorbs heat and moisture from the patients exhaled breath and uses absorbed moisture to humidify inhaled gases. Can also filter bacteria and viruses, this will be used on all patients. WARNING can affect delivered pressure.

PEEP – Positive End-Expiratory Pressure: The lower pressure applied to the patient’s airway to allow them to breathe out, but not too much.

PRVC – Pressure Regulated Volume Controlled: A mode of ventilation where a set tidal volume is delivered to the patient while maintaining the lowest pressure possible in the airway, to avoid trauma.

RF – Radio Frequency: Many medical devices are sensitive to RF interference. Care should be taken to ensure that this is kept to a minimum.

SIMV-PC – Synchronized Intermittent Mandatory Ventilation – Pressure Controlled: a mode of ventilation where the patient is allowed to take spontaneous breaths, the machine will assist the patients breathing when a spontaneous breath is taken. If the patient does not make a preset number of breaths a minute (i.e. 10) the machine provides mechanical ventilation to provide the set number.