DESIGN AND FABRICATION OF A DUAL POWERED EXTRACTOR FUME CUPBOARD

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Abstract
A dual powered extractor fume cupboard was developed with a view to solve the problem of erratic electric power supply that has hitherto hindered the utilization of the fume cupboard in most laboratories. The dual powered extractor fume cupboard was made up of three main parts which are the interior panel, ductwork/exhaust system and cabinet. The interior panel consists of the work surface, baffles, adjustable slots, and wash hand basin. The ductwork/exhaust system consists of pipes, bifurcate fan, remote blower, a battery (12Volts, 75AH) and a 1hp electric motor. The cabinet is directly beneath the work surface, and it is used for storage of the chemicals and equipment used in carrying out experiments in the hood. The fan velocity, sash movement effect and noise test of the dual power extractor fume cupboard was carried out using standard methods, while the smoke test was by visual observation. The results of the performance evaluation showed that the dual powered fume cupboard had an average fan velocity of 0.509m/s, sash movement effect of 0.53, noise test 57.4 dbA and smoke test showed effective extraction of fume from the fume cupboard. The fabricated fume cupboard will be suitable for the prevention of pollution by hazardous gases during experiments and can be categorized as a general purpose laboratory fume cupboard. The cost of production the equipment is One Hundred and Seventy Four Thousand Eight Hundred and Twenty Naira (₦174, 820), which is cheaper and affordable compared to the imported ones.

Keywords: Design, fume cupboard, fan velocity, sash movement, smoke test, noise test

Introduction
Laboratory experiments involve several procedures that have the tendency of producing hazardous/toxic gaseous components such as smoke, gaseous ammonia etc. These gaseous components can have adverse health implications on the technologist/researchers and others in the laboratory; it can as well cause environmental pollution, thereby putting the whole environment at risk. Several fume cupboards have been designed to solve these problems associated with carrying out laboratory experiments (Chemical fume hood guide, 2007, American Conference of Governmental Industrial Hygienists (ACGIH), 2004).

A laboratory fume cupboard or fume hood is a ventilated enclosure where harmful or toxic fumes or vapors can be handled safely. It is designed to provide primary exposure protection to laboratory personnel working with hazardous chemicals (Chandra and Peh, 2010). The purpose of fume cupboard is to capture, contain and remove contaminants, preventing their escape into the laboratory. This is accomplished by drawing contaminants within the hood's work area away from the operator, so that inhalation and contact are minimized (Mcleod & Glenn, 2009).

Airflow into the hood is achieved by an exhaust blower which takes "pulls" air from the laboratory room into and through the hood and exhaust system. This "pull" at the opening of the hood is measured as face velocity. A baffle, air foil and other aerodynamically designed components control the pattern of air moving into and through the hood (ACGIH), 2004). Contaminated air within the hood is then diluted with room air and exhausted through the hood's duct system to the outside where it is adequately dispersed at an acceptably low concentration (Associated Air Balance Council (AABC), 2002). A typical fume cupboard has a box like structure with a moveable sash window. Experimental procedures are performed within the hood which is consistently and safely ventilated, usually by means of an extract blower and ductwork (Saunders, 1993).

The fume cupboard functions by maintaining a relatively negative pressure inside the hood to prevent contaminants from escaping, and takes in air through the hood opening at a consistent rate. A suitable hood face velocity (the speed at which air is drawn into the hood) is of importance to the safe and effective operation of a fume hood. While excessive face velocities can often result in turbulence and reduce containment, insufficient velocities can also compromise hood performance. In general, a hood's face velocity is recommended to be between 0.3 m/s (60 fpm) and 0.5 m/s (100 fpm) (Chemical fume hood guide, 2007, Laboratory fume hood, 2013). A fume cupboard does not function alone and a variety of external factors such as its location inside the laboratory and the laboratory ventilation can influence its performance. The users must ensure that the fume cupboard functions well in the laboratory system before work commences and it is properly used (Labconco, 2003, Mills & Dale, 2006).

However, fume cupboards are not locally produced in Nigeria, but are usually imported; making it expensive. Problems are encountered in the maintenance of the few imported fume cupboard available, these problems includes unavailability of spare parts, very few skilled personnel are available to carry out routine, corrective, preventive or breakdown maintenance of the fume cupboard (Chandra & Peh, 2010, Chemical fume hood guide, 2007). All existing types of fume cupboard are electrically operated so constant electric power supply is also a major constraint in the usage of imported fume cupboard in Nigeria due to the erratic power supply. Hence the need to design and fabricate a dual powered extractor fume cupboard that will be relatively cheaper with readily available spare parts and has the ability to use other alternate source of power in time of power failure.

Materials and methods

Design Considerations

The factors considered in the design and fabrications of a dual power extractor fume cupboard as recommended by Wesolowski *et al.* (2010); Chemical fume hood guide, (2007); Mills and Dale, (2006) are:

i. Location of the Fume Cupboard: In designing a fume cupboard, the location/position in which the fume cupboard was first considered. The fume cupboard was located away from normal traffic pattern, cross-draughts, air inlets and other sources of disturbance. It was installed not face to face or directly opposite a biological safety.
ii. Strength and rigidity: Materials with high strength and rigidity were selected for the fabrication of the fume cupboard, so that it can withstand loads of material without collapsing.
iii. Ease of operation: The fume cupboard can be easily operated by students or staffs with little information on the fume hood systems. It can be operated by an unskilled labour with little training.
iv. Maintenance: Component parts will be easily removed and maintain periodically.

v. Noise Control: The fume cupboard was designed aerodynamically to reduce the noise passing through it. Well sized duct components fitted with the minimum number of 90 degrees elbows reduces air movement noise. Installing the blower outside the laboratory above 10 feet from the ground keeps the single largest source of noise away from the work place.

vi. Power Failure: The fume cupboard was designed with a dual powered extraction method, primarily to solve the problems of unforeseen power failure. The axial fume extractor was powered by an Alternating Current (AC) power source, which uses Direct Current (DC) when there is electric power from the mains and switches back to AC power when there is power failure.

vii. Ergonomic consideration: The height of the hood in which the experiments are to be carried out was considered with respect to human height. The operational height of the fume cupboard has been chosen from within acceptable limit of 1.2m assumed to be the average human height. The overall height of the fume cupboard from the top of the hood to the floor where it stands is 2.6m.

viii. Affordability: In order to reduce cost the fume cupboard without compromising the engineering properties and safety, locally available raw materials with suitable mechanical properties were selected.

Material Selection

The list of materials and the criteria for selection for the various parts of the fume cupboard are as presented in Table 1.

Table 1: List of materials selected and selection criteria

S/N	Fume cupboard component	Criteria for selection	Most suitable material	Material actually selected	Reason for selecting the material
1	Hood body		Wood	Wood	Readily available, meets the requirement and cheap.
2	Sash	It should be 6.4 mm thick laminated safety glass in a corrosion-resistant PVC track	Glass	Glass	Meets the standard criteria for selection, readily available.
3	Ductwork	Must be able to contain fume moving at high velocity without causing any damage to its self.	PVC/ mild steel metal sheet	PVC pipes and metal 90 degree elbow	Readily available, light weight, meets the requirement.
4	Remote blower (centrifugal fan)	It must be suitable for moving large volumes of air.	Centrifugal fan	Centrifugal fan.	Easily fabricated with readily available material.
5	Work surface	Should not react when in contact with chemicals used in the hood.	Wood / tiles	Wood covered with Formica	It does not cause acidic reaction that forms harmful compound
6	Baffles	It should be the same material with the one	Wood	MDF Wood	Cheap, meets requirement,

		used for the hood body			readily available.
7	Bifurcate fan blade	Must be flexible and must not weight too much.	Plastic/PVC	Plastic	Less weight, more flexible.
8	Cabinet	It should be able to support the weight of the work surface and the equipment in the hood.	Wood	Wood	Cheap, readily available, reliable and not easily deflected.
9	Wash hand basin	Does not easily react with chemicals.	Ceramic	Ceramic	Does not easily react with chemicals.
10	Sash handle		Stainless steel	Stainless steel	Cheap and readily available

Design Analysis and Calculations

Fume hood are generally available in Five (5) different width, depth and height ranging from 1000 to 1800mm, 700 to 900mm depth and height 1900 to 27000mm respectively (Pickard, 2002). The dimensions and specifications for the various component parts of the fume cupboard were selected within the range recommended by Pickard, 2002, Chemical Hood Guide, 2007; Labconco, 2003 & Chemical fume hood, 2013. The selected dimensions were used for the design calculations of the component parts of the fume cupboard as presented in Table 2.

Table 2: Dimension of component parts of the fume cupboard

S/no	Specifications of component	Dimension
1	External dimension (Lx B x H)	1300 x 905 x 1500mm
2	Internal dimension (Lx B x H)	1220 x 710 x 960mm
3	Maximum sash opening	580mm
4	Recommended maximum and minimum exhaust air volume for minimum face velocity of 0.5% at half open sash position	Maximum: 990 x 10^6mm^3 Minimum : 10 x 10^6mm^3
5	Bifurcate fan housing inlet diameter	Inner (x):100mm Outer(y) :185mm
6	Bifurcate fan housing	Height of big cone (H): 480mm, radius: 185mm Height of small cone (h): 260mm; radius: 100mm
7	Exhaust pipe (45^o elbow) radius and length (short h_1)	100mm; 2720mm
8	Exhaust pipe (90^o elbow) radius and length (long h_2)	100mm; 3800mm
9	Electric motor pulley diameter (D_2)	120mm
10	Machine pulley diameter (D_1)	50mm
11	Electric motor speed	1400rev/min
12	Distance between the machine pulley and electric (x) motor pulley	390mm

a. Volume of Fume of work space (Vc)

The volume of the work space (Vc) of the fume cupboard was calculated using the formula:

$Vc = L \times B \times H$ 1

Where:

L = Length of the fume cupboard

B = Breath of the fume cupboard

H = Height of the fume cupboard

Vc = 1220mm x 710mm x 960mm

$Vc = 831.552 \times 10^6$ mm^3

b. Volume of the bifurcate fan housing (Vb)

The volume of the bifurcate fan housing (Vb) for the extraction the fume was calculated using the formula for the volume of pyramid = п/3 base area x height.

$Vb = \pi/3\ (y^2H - x^2h)$ 2

Where y = Radius of the big circumference

x = Radius of the small circumference

H = Total height of the cone

h = Height of the small cone

$Vb = \pi/3\ [(185^2 \times 480) - (100^2 \times 260)]$

$Vb = \pi/3\ [(34{,}225 \times 480) - (10{,}000 \times 260)]$

$Vb = \pi/3\ (16{,}428{,}000 - 2{,}600{,}000)$

$Vb = \pi \times 13{,}828{,}000/3$

$Vb = 14{,}482{,}525.33\ mm^3$ or $14.483 \times 10^3\ cm^3$

Volume of the bifurcate fan housing (Vb) = $14.483 \times 10^6\ mm^3$

c. Volume of the pipes (Vp)

The pipes for the conveyance of fumes from the fume cupboard consist of the short pipe (attached to the work space) and the long pipe (attached to the short pipe and extends to the outside of the laboratory area). The volumes of the short ($Vp_{1)}$ and long (Vp_2) pipes are calculated using the formula for the volume of a cylinder given as:

Volume of a cylinder = $\pi r^2 h$ 3

Where:

Vp_1 = volume of the short pipe

Vp_2 = volume of the long pipe

h_1 = length of short pipe = 2,270mm

h_2 = length of long pipe = 3,800mm

r = radius of pipe = 100mm

$Vp_1 = \pi \times 100^2 \times 2{,}720$

$Vp_1 = 85{,}462{,}400\ mm^3$ or $85.462 \times 10^6\ mm^3$

$Vp_2 = \pi \times 100^2 \times 3{,}800$

$Vp_2 = 119{,}396{,}000\ mm^3$ or $119.396 \times 10^6\ mm^3$

Volumes of the short and long pipes are $85.462 \times 10^6\ mm^3$ and $119.396 \times 10^6\ mm^3$ respectively.

d. Design of the fan speed and belt length

The fan speed of was calculated using the formula given by Gary et al. 2004 (Figure 1) as:

$D_1N_1 = D_2N_2$ 4

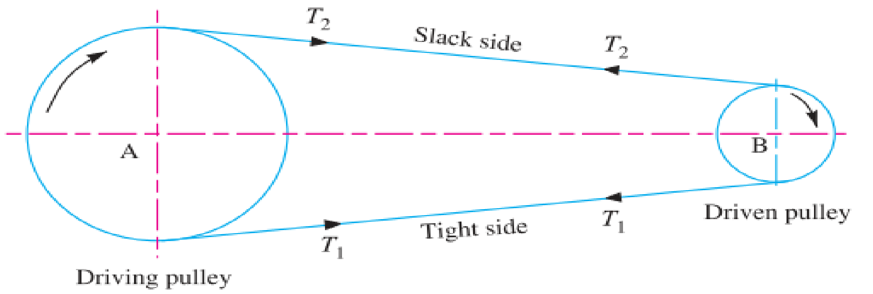

Figure 1: Belt and pulley mechanism (Gary *et al.,* 2004)

Where:
Motor pulley diameter D_1 = 120mm
Machine pulley diameter D_2 = 50mm
Electric motor speed N_1 = 1400 rev/min
Speed of the fan shaft N_2= ?
Therefore $N_2 = D_1N_1/D_2$
N_2 = 120 x 1400/ 50
N_2 = 3,360 rev/min or 56 rev/sec
Since the fan blades are directly connected to the shaft, it is therefore assumed that the speed of shaft is equal to the speed of fan.
The length of belt was calculated using the formula given by Khurmi and Gupta, 2005 as:

$$L = \frac{\pi}{2}(D_1 + D_2) + 2x\frac{(D1- D2)2}{4x} \qquad 5$$

Where:
D_1 = diameter of the larger pulley
D_2 = diameter of the smaller pulley
x = distance between the two pulleys
L = total length of the belt
Substituting;

$$L = \frac{3.142}{2}(120+ 50) + 2 \times 390\,\frac{(120 - 50)2}{4 \times 390}$$

$$L = (\frac{3.142}{2}\,170) + (780 \times \frac{11900}{1560})$$

L = (1.571 x 170) + (780 x 7.628)
L = 267.07 + 5949.84
L = 6,216.91 mm.

Fabrication of Components parts

The component parts of the dual power extractor fume cupboard are fabricated using the appropriately selected materials and standard methods. The components fabricated are:

a. Fume cupboard interior and cabinet

The fume cupboard interior and cabinet are made from wood. The dimensions were accurately measured and cut out as presented in Table 1. The rectangular shape was developed and coupled together with nails, bolts and nuts. The work space of 1220mm x 710mm x 960mm has a volume of 831.552 x 10^6 mm^3 which is the main hood where experiments are conducted. The wok space consists of baffles which are used to adjust the air flow rate. While the lower section is the cabinet where the chemicals use for experiments are stored. The wash hand basin was fixed after the entire wood work.

b. Centrifugal fan/blower

The centrifugal blower was made of mild steel metal sheet. The six (6) fan blades of 210mm x 150mm were marked on the metal sheet and cut out with the use of a metal sheet cutter. The six blades were welded to the mild steel shaft with equal spacing. The mild steel shaft has a diameter of 20mm and length of 390mm. A pulley of 50mm was attached to the end of the shaft, and two (2) ball bearings were used to hold the shaft firm to the frame work with the aid of 17 size bolts and nuts. A V-belt of size A40 was used to connect the pulley of the electric motor which is 120mm in diameter to the pulley of the machine. The frame work was fabricated with the use of angle iron of 50mm x 50mm. All component parts were joined together using arc welding (Plate 1). The fan was powered by an electric motor (1hp) with the use of belt and pulleys. The fan is housed in a metal case and supported by frame work. The centrifugal blower is a type of suction fan that sucks in air horizontally and blows it away vertically.

c. Bifurcate fan

The bifurcate fan was fabricated with a housing which encloses the fan blades and the rotor. The bifurcate fan has eight (8) fan blades with a joint diameter of 380mm, while the fan blades were joined to the rotor (Plate 2). The bifurcate housing was fabricated into a hollow cone shape with the big and small diameter of 370mm and 200mm respectively, and a height of 220mm with a volume of 14.483×10^6 mm^3. The bifurcate fan extracts air directly from the fume hood, it has a cone shape covering designed to house the bifurcate fan. It is placed at the top of the fume hood.

d. Angles 45 and 90 elbow pipe

The angles 45 and 90 elbow pipes were designed to change the direction of flow of the fume from the pipe by 45° and 90° respectively (Plate 3 and Plate 4). The metal sheet were marked and cut out with the use of metal sheet cutter. The circumference of the pipes marked was 3142mm, which gave a diameter of 200mm. Electrodes were used to weld the metal sheets together to form the desired shapes. The volumes of the short and long pipes are 85.462×10^6 mm^3 and 119.396×10^6 mm^3 respectively.

Each of the fabricated component parts of the fume cupboard was assembled together with a 12Volts, 75AH battery attached to serve as an alternative source of power. Therefore the fume cupboard can be operated in the absence of AC electric current from the mains.

Plate 1: Bifurcate fan/blower

Plate 2: Centrifugal fan/blower

Plate 4: Angle 45 elbow pipe

Plate 5 : Angle 90 elbow pipe

Performance evaluation

The following operation procedures were followed as described by Laboratory fume hood, 2013 for the testing of fume cupboard. All doors and windows in the laboratory where closed and the fume cupboard extraction fans switched on. All items that could be an obstruction to the airflow were removed from the fume cupboard and measurements were taken with an anemometer. The sash was set to an opening height of 460mm; this is the height from the bottom edge of the sash above the lip or raised edge of the working surface. The anemometer was placed in the sash opening, ensuring that it is correctly orientated in the airflow, which is usually indicated by a flow direction arrow on the anemometer housing. Image of the sash opening was divided into nine equal rectangles (Figure 2). A distance of 300mm was given when taking the readings with an anemometer. The sensing head of the anemometer was placed at the center of each rectangular plane of the sash, so as to get accurate readings. Record for each rectangle was taken three (3) times.

$X_{(1)}$	$X_{(2)}$	$X_{(3)}$
$X_{(4)}$	$X_{(5)}$	$X_{(6)}$
$X_{(7)}$	$X_{(8)}$	$X_{(9)}$

Figure 2: Grid points across the sash opening

a. Sash Movement Effect (SME)

The procedures as described in *ANSI/ASHRAE 110-1995* were followed for testing the sash movement effect. After 60 seconds of operation of the fume cupboard, the sash was opened to the design position. After 60 seconds of opening, the sash was closed. Thirty (30) seconds after closing the sash, the sash was opened again to the design position. Opening and closing of the sash were repeated to obtain readings for three cycles. 45-second rolling averages for each of the three "sash opening" periods were determined. Readings for the three cycles of the rate at which the air enters the fume cupboard were determined.

b. Noise Test

The noise test was carried out using the procedures described by Laboratory fume hood, 2013 and Chemical fume hood handbook, 2009. The sash was placed in design position and ensured that the face velocity was approximately 0.5 m/s. Noise level meter was placed in front of the fume hood at the working position, 300 mm out from the plane of the sash and 1.2 m above floor level. Five (5) noise level readings were taken in Thirty (30) seconds, with an interval of 6seconds each. Noise level readings were record in dBA, and the average reading over a 30-second time frame was determined.

c. Smoke Visualization Tests

Due to the lack of smoke visualization testing apparatus in the laboratory, visual assessments were used to determine the escape rate of the smoke. The fume cupboard was initially put off and the sash of the fume cupboard was raised up to the designed opening height. Sheet of papers were put in a can, and placed in the work surface of the fume cupboard. The papers were lit, and immediately the sash was lowered to the designed closing height. The smoke from the paper escapes from the fume cupboard through the open space of the sash, and partially through the duct system. The smoke escaping the fume cupboard was visualized with mere eyes. The fume cupboard was then turned on and the smoke coming out of the fume cupboard through the sash opening was no longer visible, but the smoke extracted through the ductwork system becomes denser and dark.

Result and Discussion

The fabricated fume cupboard (Plate 5) was made up of three main parts which are the interior panel, ductwork/exhaust system and cabinet. The interior panel consists of the work surface, the baffles, the adjustable slots, and the wash hand basin. The interior panel is where all the chemical experiments are carried out; it has 5 wooden sides and a glass side to enclose it. The ductwork/exhaust system consists of pipes, the bifurcate fan, the remote blower, a 12Volts, 75AH battery and a 1hp electric motor. The electric motor is placed outside the building at a 10meters high; it is used to power the remote blower (centrifugal fan) which sucks fume from the pipes coming from the fume hood. The bifurcate fan is placed directly on the fume hood so as to suck the fume out of the hood into the pipes. In the case of power failure, the axial fan will be powered by the 12Volts battery. The cabinet is directly beneath the work surface, and it is used for storage of the chemicals and equipment used in carrying out experiments in the hood. The cost of production of the dual powered extractor fume cupboard was One Hundred and Seventy Four Thousand Eight Hundred and Twenty Naira (₦174, 820) which is cheaper than the imported ones which ranged between #1,000,000 and #5,000,000 depending on the capacity and other accessories.

Plate 3: The fabricated Fume cupboard

Face velocity of the dual powered fume cupboard

The results of the face velocity test are as presented in Table 3. The average face velocity reading for each test was 0.511 ms^{-1}, 0.511 ms^{-1} and 0.506 ms^{-1} respectively. The overall average face velocity of the tested fume cupboard was 0.509 ms^{-1}. The face velocity of the developed dual powered fume cupboard was within recommended standard for face velocity suitable for most hazardous experiments (Table 4).

Table 3: Face velocity test results of the dual powered Fume Cupboard

Test Number	Face Velocity at a given Grid Point at 0.5m sash opening height (ms^{-1})									Face velocity mean (ms^{-1})
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	
1	0.49	0.5	0.49	0.51	0.52	0.51	0.53	0.52	0.53	0.511
2	0.5	0.5	0.49	0.51	0.52	0.51	0.52	0.53	0.53	0.511
3	0.49	0.49	0.5	0.5	0.51	0.51	0.52	0.52	0.52	0.506

Table 4: Comments on the different face velocities of a fume cupboard

Face velocity (ms^{-1})	Comments
≥0.7	Suitable for all work, including work with the highest hazard materials, e.g. highly toxic or radioactive materials. However, containment can be significantly reduced at velocities >1ms^{-1} due to the effects of turbulence.
≥0.5	Generally suitable for most hazardous materials. A velocity of 0.5ms^{-1} at a sash opening of 0.5m is the accepted 'norm' for a general purpose laboratory fume cupboard.
≥0.3	Low hazard work only, or use as a ventilated enclosure (e.g. a designated storage area).

(Aston University, 2007)

Sash Movement Effect (SME) of the dual powered Fume Cupboard

The results of the SME test for the developed dual powered extractor fume cupboard are as presented in Table 5. The readings for the three cycles of the rate at which the air enters the fume cupboard are 0.53 ms^{-1}, 0.54 ms^{-1}, and 0.53 ms^{-1} respectively. The overall average airflow reading affected by the sash movement is approximately 0.533 ms^{-1}. Hence, the effect of sash movement on the airflow rate in the fume cupboard also falls within the generally accepted face velocity range for the sash set to 500mm height, which is 0.5 ms^{-1} ± 10% (American Industrial Hygiene Association (2003).

Table 5: Sash movement effect airflow result

Readings	First 60 seconds (ms^{-1})	Next 60 seconds (ms^{-1})	Last 60 seconds (ms^{-1})
1	0.54	0.55	0.55
2	0.54	0.53	0.53
3	0.52	0.53	0.52
Mean readings	0.53	0.54	0.53

Noise Test of the dual powered Fume Cupboard

The results of the noise test for the dual powered fume cupboard are as presented in Table 6. The results showed that the maximum, average, and minimum noise level produced by the fume cupboard are 57.4 dBA, 57.14 dBA, and 56.8 dBA respectively. The maximum noise exposure level for an Eight (8) hours working day is 85 dBA (ANSI/ASHRAE, 1992).

Hence, the maximum noise produced by the fume cupboard (57.4 dBA) is lower than the maximum noise exposure level for an Eight (8) hours working day.

Table 6: The noise test for the dual powered fume cupboard

Frequency (interval of 6s)	Sound level meter Readings (dBA
1	56.8
2	57.3
3	57.4
4	57.3
5	57.1

Smoke test of the dual powered Fume Cupboard

The summary of result of the smoke test for the dual powered fume cupboard is as presented in Table 7. The results showed that the dual powered extractor fume cupboard was effective in extracting smoke through the duct system.

Table 7: The result of the smoke test for the dual powered fume cupboard

Fume cupboard	Initial observation	Final observation
OFF	The smoke from the burning can was seen coming out through the sash opening.	The smoke was seen coming out partially through the duct system and the opening.
ON	The smoke coming out of the fume cupboard through the sash opening was slightly seen.	The smoke coming out of the fume cupboard through the sash opening was no longer visible, but the smoke extracted through the duct system was clearly seen.

Conclusion

The developed dual powered fume cupboard which is comparatively cheaper than the imported ones, can be categorized under the general purpose laboratory fume cupboard which is suitable for handling most hazardous materials emission during experiments. It is however recommended that an LCD (liquid crystal display) warning display unit be installed to display malfunction source when the fume cupboard is in operation.

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