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Triboelectric Nanogenerators Enhanced by Metal-Organic Framework for Sustainable Power Generation and Air Mouse Technology

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Equal contribution

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Materials characterizations

Materials:

2 aminotetrephalic acid and azo pyridine were procured from Sigma Aldrich, and methanol, and acetone was procured from SRL chemicals. Deionized water was used throughout the study. All the materials were utilized as such without any further purification.

Physical Measurements

The Single crystal data were collected by using graphite-monochromated Mo Kα radiation (λα = 0.71073 Å). Thermogravimetric analysis (TGA) was recorded with a METTLER TOLEDO (TGA/DSC1) system through STARe software by a heating rate of 10 °C/min in an N_2 atmosphere up to 800 °C. For the Powder X-ray diffraction (PXRD) analysis, Cu Kα (0.154 nm) monochromatic radiation was used with a Rigaku Smart Lab X-ray diffractometer. The morphologies were investigated by a Supra55 Zeiss field emission scanning electron microscope (FESEM). Brunauer−Emmett−Teller (BET) surface area and Barrett−Joyner−Halenda (BJH) distribution determinations were conducted on an Autosorb iQ (Quantachrome Instruments, version 1.11). The output performance of the device, load matching analysis, stability, and commercial capacitor charging study were measured using a Keithley 6514 electrometer.

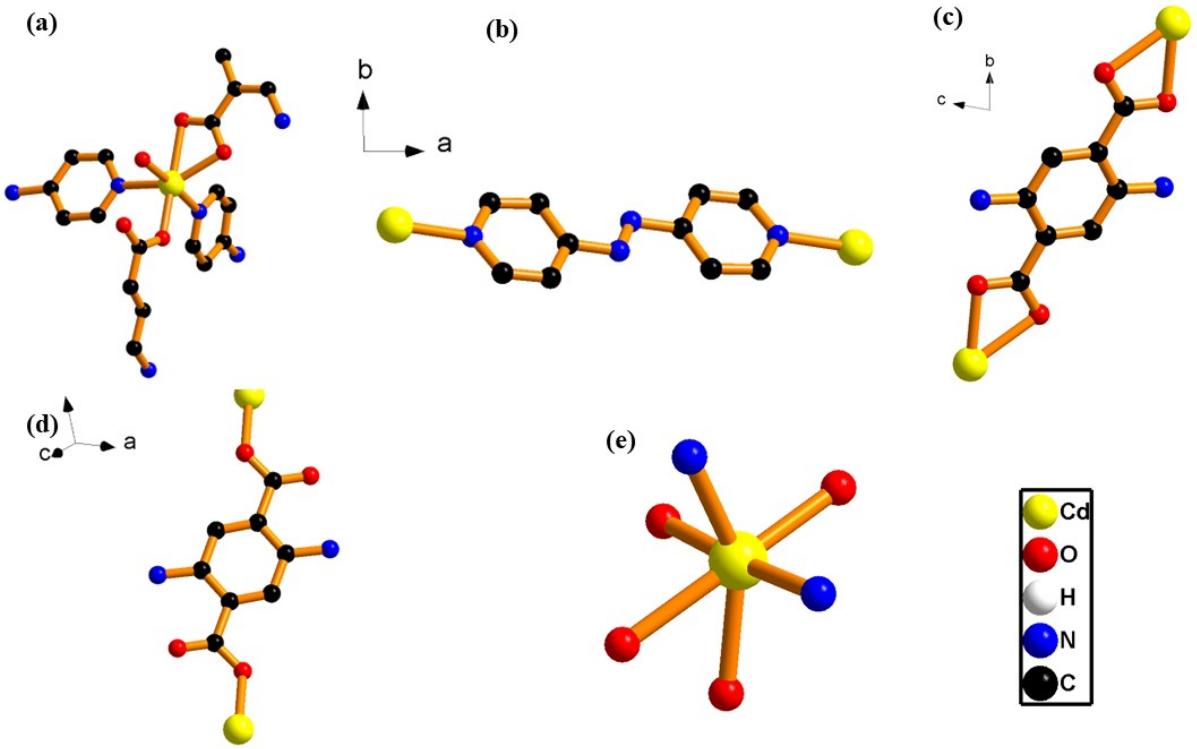

Fig S1. (a)The asymmetric unit of Cd-MOF (b) AzPy binding mode (c-d) 2ATA-binding mode (e) metal binding mode.

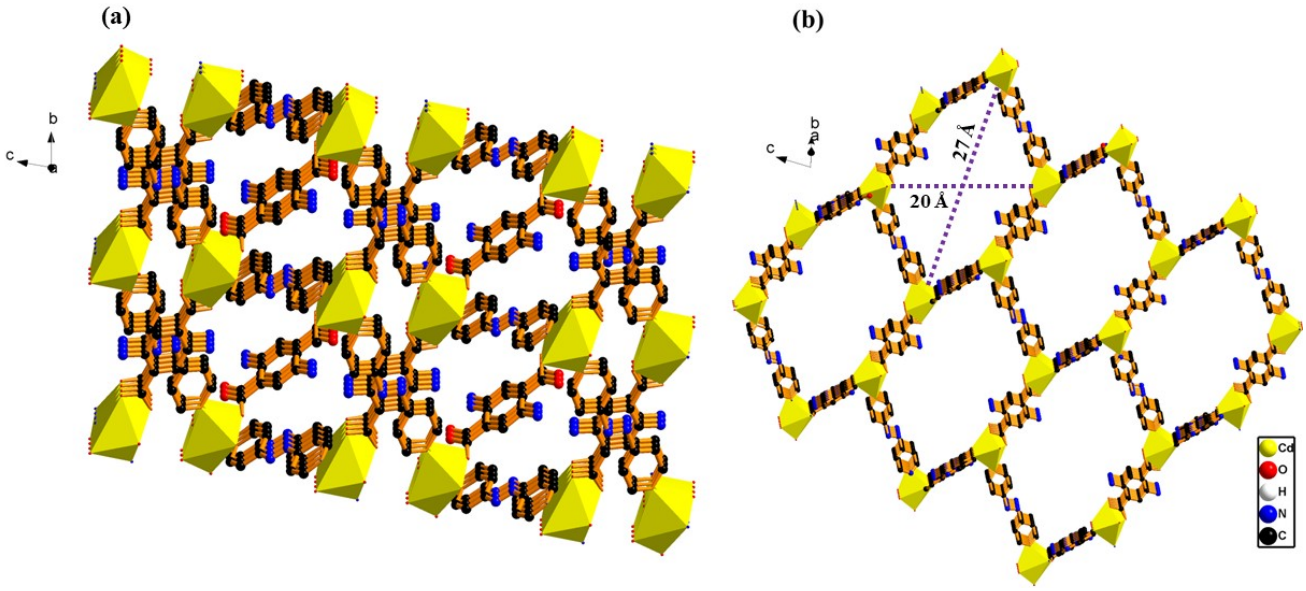

Fig S2. (a) 2D network of Cd-MOF along a-axis with polyhedra (b)Porous nature of Cd-MOF having metal-metal pore aperture.

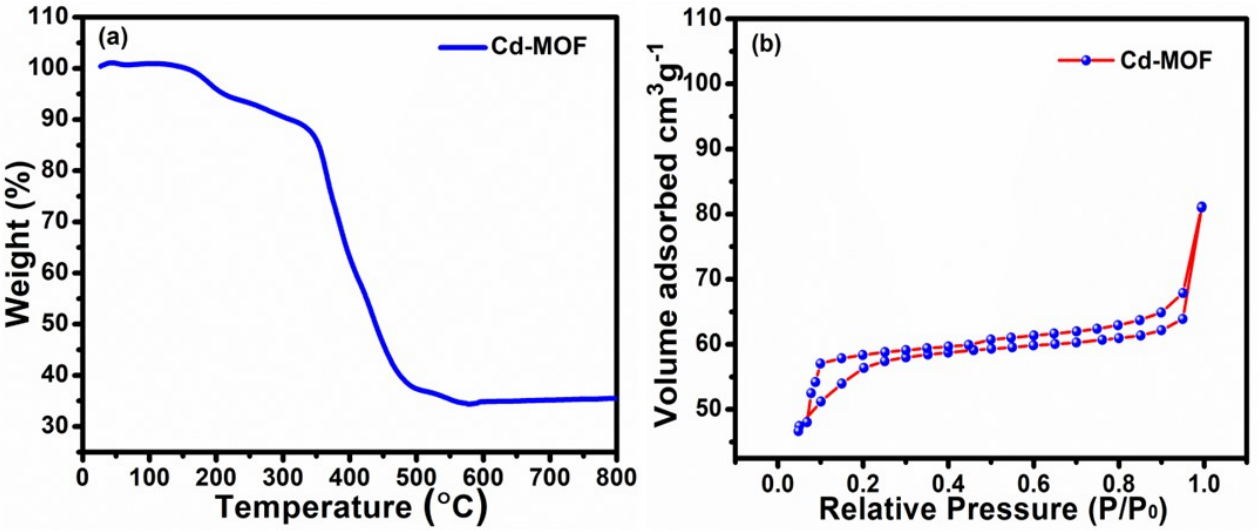

Fig S3. (a) Thermogravimetric analysis curve of Cd-MOF (b) BET analysis of Cd-MOF.

Sample Details

Sample Name:	CD-MOF 2		
SOP Name:	mansettings.nano		
General Notes:			
File Name:	Since Dec 2021.dts	**Dispersant Name:**	Water
Record Number:	1251	**Dispersant RI:**	1.330
Date and Time:	Monday, September 26, 2022 5:2...	**Viscosity (cP):**	0.8872
		Dispersant Dielectric Constant:	78.5

System

Temperature (°C):	25.0	**Zeta Runs:**	12
Count Rate (kcps):	181.6	**Measurement Position (mm):**	2.00
Cell Description:	Clear disposable zeta cell	**Attenuator:**	4

Results

			Mean (mV)	Area (%)	St Dev (mV)
Zeta Potential (mV):	-16.2	**Peak 1:**	-16.2	100.0	4.71
Zeta Deviation (mV):	4.71	**Peak 2:**	0.00	0.0	0.00
Conductivity (mS/cm):	0.0900	**Peak 3:**	0.00	0.0	0.00
Result quality :	Good				

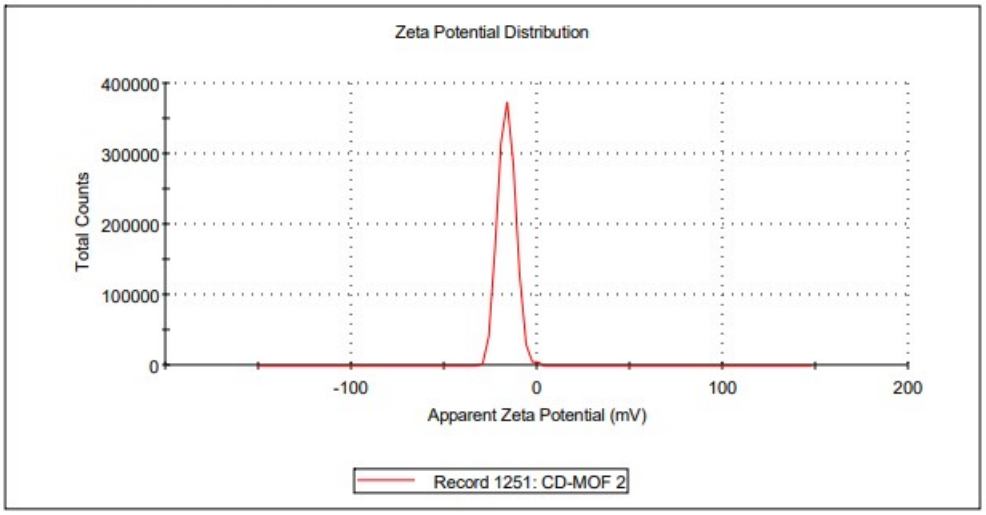

Fig S4. Zeta potential summary and Zeta potential plot of Cd-MOF.

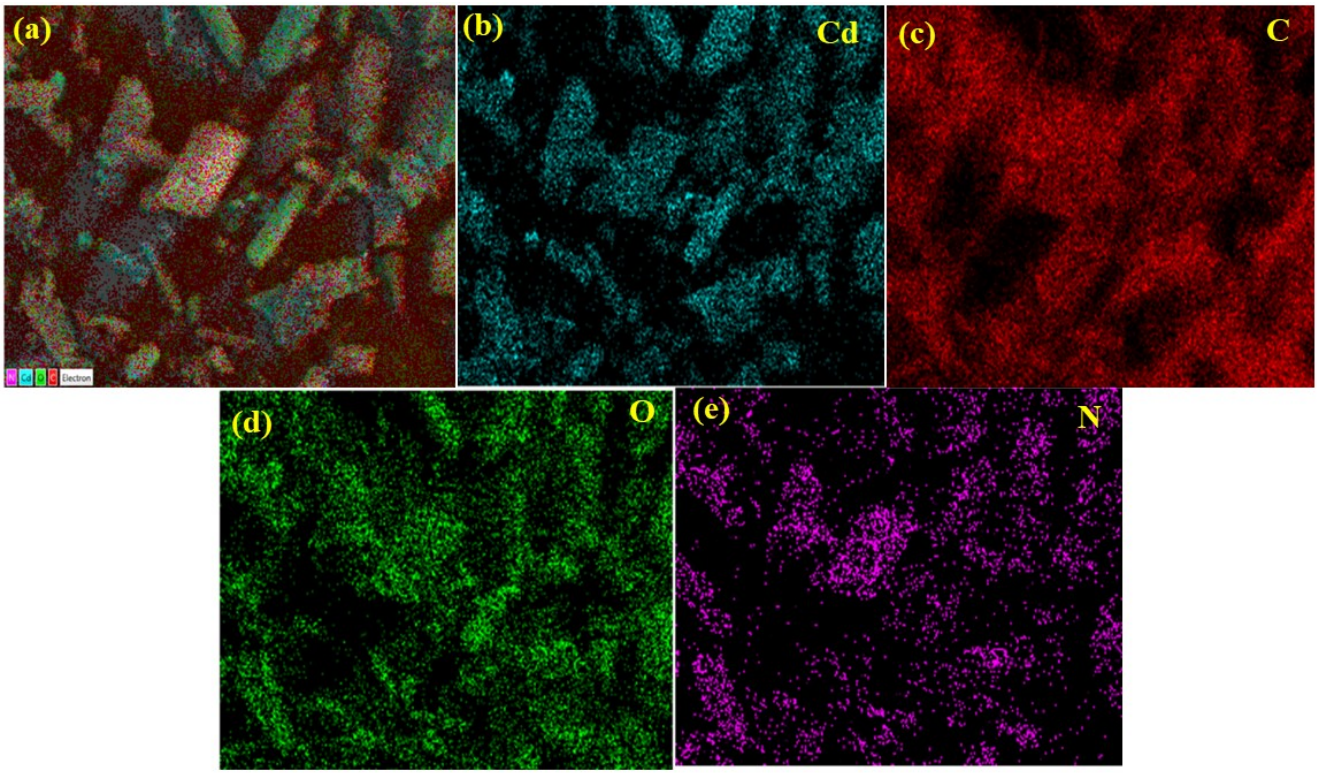

Fig S5. EDS mapping of Cd-MOF (a) SEM (b) Cd (c) C (d) O (e) N.

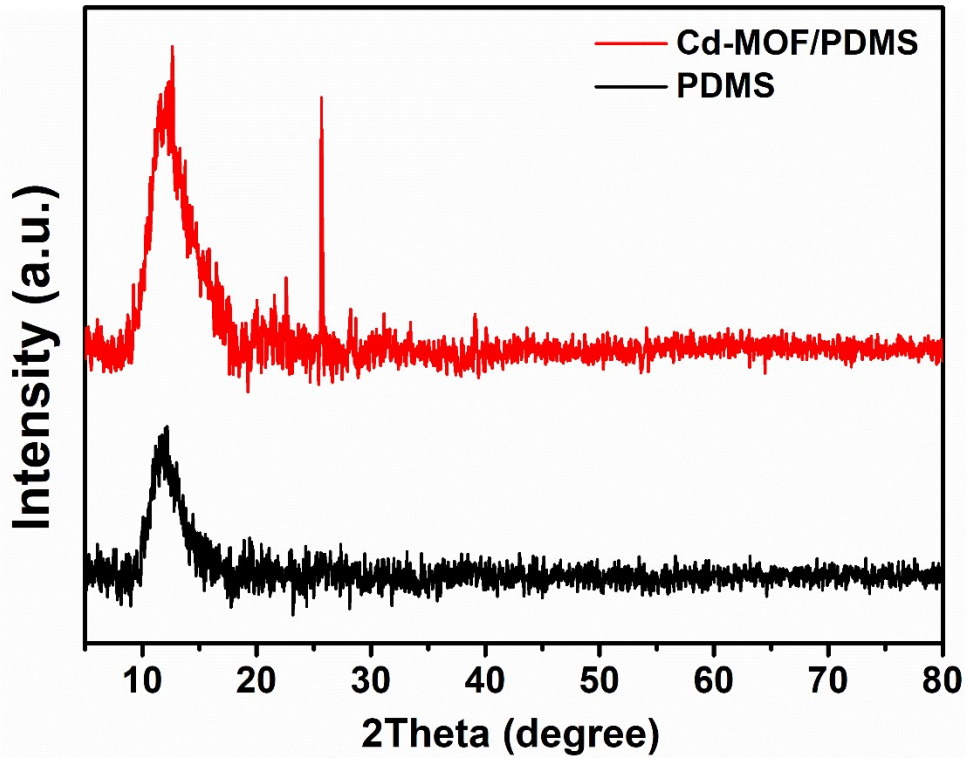

Fig S6. XRD pattern of PDMS and Cd-MOF/PDMS films.

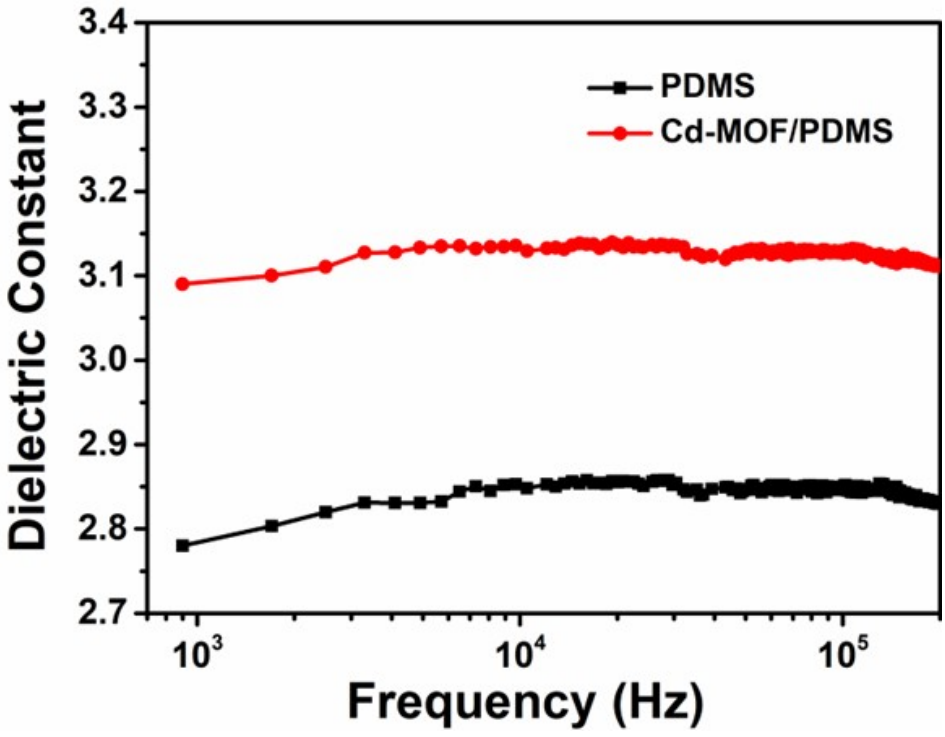

Fig S7. Dielectric constant of PDMS and Cd-MOF/PDMS films.

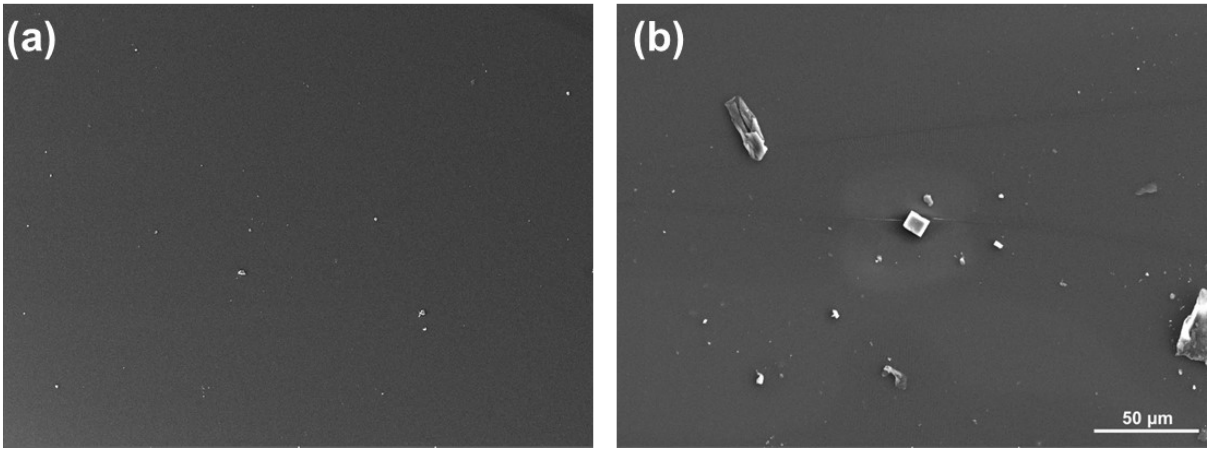

Fig S8. FE-SEM images of (a) PDMS and (b) Cd-MOF/PDMS.

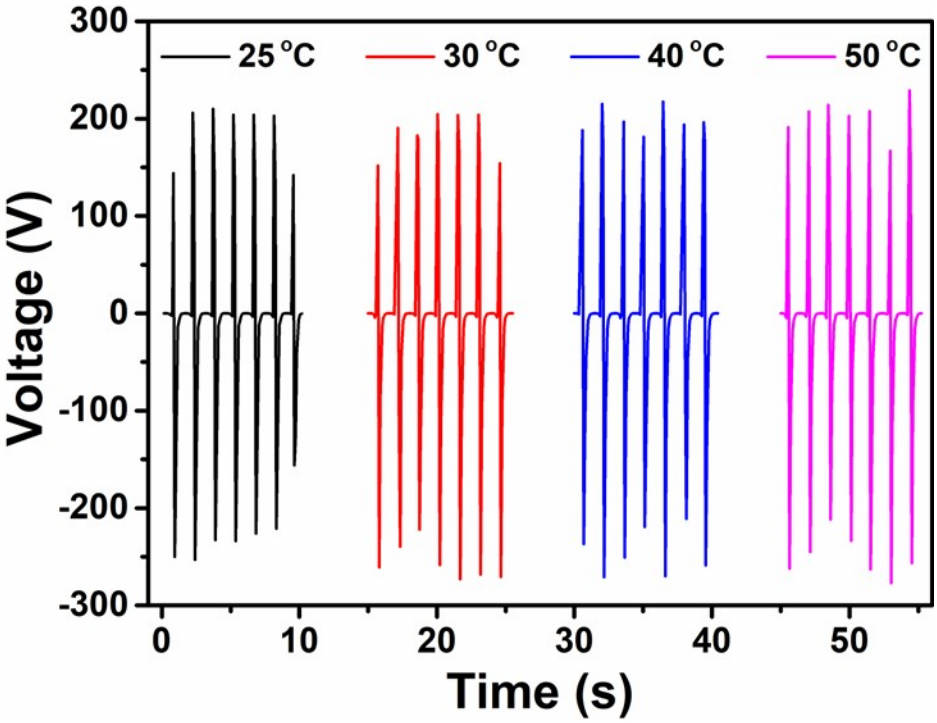

Fig S9. Output voltage under different temperature conditions from 25 °C to 50 °C.

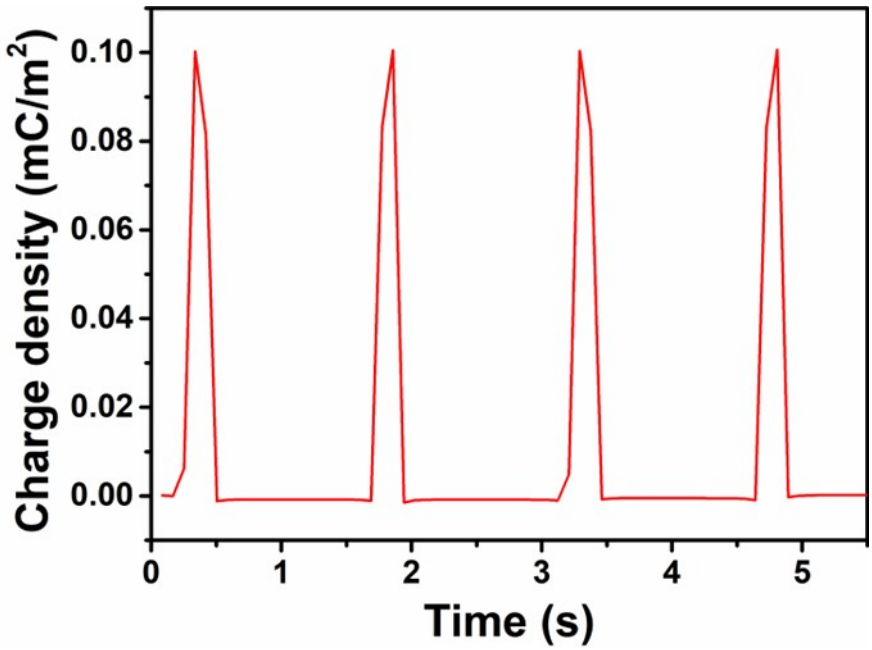

Fig S10. Output charge of the MOF-TENG.

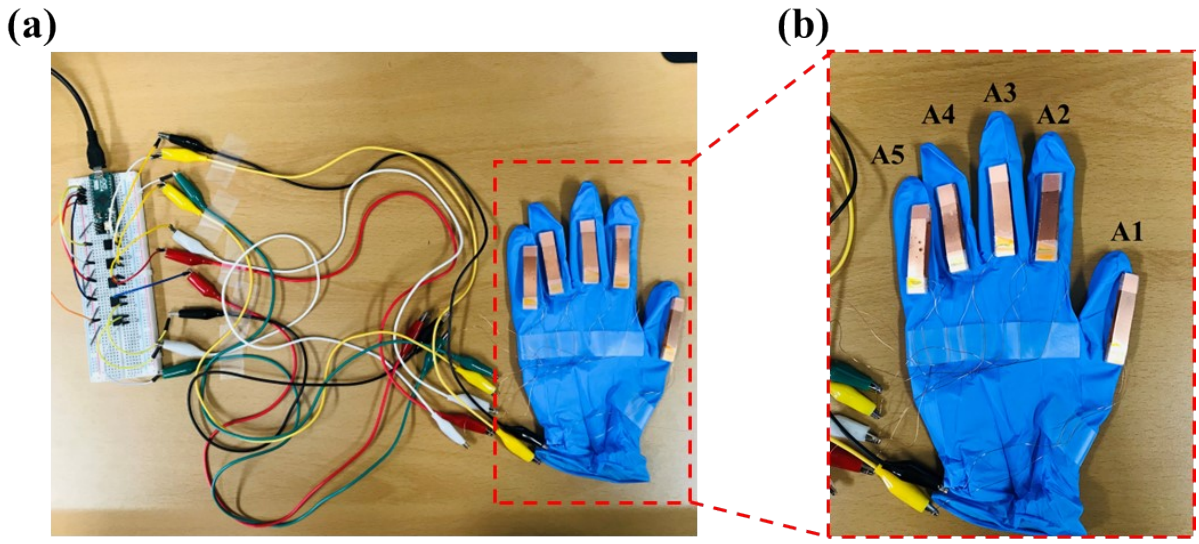

Fig S11: Digital image of (a) the air mouse setup with all the connections, (b) the glove with the MOF-TENG device attached to the fingers.

Table S1. X-ray crystal structure data and refinement parameters of Cd-MOF.

Parameters	**Cd-MOF**
empirical formula	C18 H14 Cd N5 O5
formula weight	492.74
crystal system	Triclinic
space group	*P-1*
a (Å)	7.3686(2)
b (Å)	9.9882(3)
c (Å)	13.8896(5)
α (deg)	80.054(3)
β (deg)	78.548(2)
γ (deg)	88.975(2)
wavelength (nm)	0.71073
V (Å^3)	986.71(5)
Z, d_{calcd} (mg m^{-3})	2, 1.658
temperature (K)	293(2) K
θ range/deg	3.038 to 29.209 deg.
goodness-of-fit (GOOF)	1.063
R_1, a wR_2b [I > 2σ(I)]	R1 = 0.0427, wR2 = 0.1113
R_1, *a* wR_2 b (all data)	R1 = 0.0460, wR2 = 0.1139
absorption correction	Semi-empirical from equivalents
Limiting indices	-9<=h<=9, -13<=k<=12, -18<=l<=16
crystal size (mm^3)	0.420 x 0.230 x 0.180 mm
refinement method	Full-matrix least-squares on F^2
Reflections collected / unique	11056 / 4697 [R(int) = 0.0339]
F (000)	490
CCDC no.	**2287569**

Table S2. Selected bond lengths (Å) and bond angles (˚) for Cd-MOF.

Bond Length (Å)	
Cd(1)-O(3)	2.228(2)
Cd(1)-O(1)	2.306(3)
Cd(1)-O(5)	2.309(3)
Cd(1)-N(2)	2.328(3)
Cd(1)-N(1)	2.352(3)
Cd(1)-O(2)	2.434(3)
Cd(1)-C(1)	2.720(3)
O(1)-C(1)	1.263(5)
O(2)-C(1)	1.264(5)
O(3)-C(5)	1.262(4)
O(4)-C(5)	1.237(5)
O(5)-H(5A)	0.8501
O(5)-H(5B)	0.85
N(1)-C(13)	1.323(6)
N(1)-C(9)	1.325(6)
N(2)-C(18)	1.320(6)
N(2)-C(14)	1.340(6)
N(3)-C(4)	1.334(8)
N(3)-H(3A)	0.86
N(3)-H(3B)	0.86
N(4)-C(8)	1.400(10)
N(4)-H(4A)	0.86
N(4)-H(4B)	0.8599
C(1)-C(2)	1.499(4)
C(2)-C(3)	1.384(5)
C(2)-C(4)	1.399(5)
C(3)-C(4)1	1.397(4)
C(3)-H(3)	0.93
C(5)-C(6)	1.510(5)
C(6)-C(7)	1.370(6)
C(6)-C(8)	1.404(5)

C(7)-C(8)2	1.402(5)
C(7)-H(7)	0.93
C(9)-C(10)	1.389(6)
C(9)-H(9)	0.93
C(10)-C(11)	1.374(7)
C(10)-H(10)	0.93
C(11)-C(12)	1.357(8)
C(11)-N(5)	1.454(6)
N(5)-N(5)3	1.208(8)
C(12)-C(13)	1.375(7)
C(12)-H(12)	0.93
C(13)-H(13)	0.93
C(14)-C(15)	1.362(7)
C(14)-H(14)	0.93
C(15)-C(16)	1.358(9)
C(15)-H(15)	0.93
C(16)-C(17)	1.375(9)
C(16)-N(6)	1.503(7)
N(6)-N(6)4	1.177(11)
C(17)-C(18)	1.369(7)
C(17)-H(17)	0.93
C(18)-H(18)	0.93
Bond Angle (degree)	
O(3)-Cd(1)-O(1)	120.70(11)
O(3)-Cd(1)-O(5)	87.68(10)
O(1)-Cd(1)-O(5)	91.86(11)
O(3)-Cd(1)-N(2)	93.21(12)
O(1)-Cd(1)-N(2)	145.92(12)
O(5)-Cd(1)-N(2)	92.91(11)
O(3)-Cd(1)-N(1)	89.69(11)
O(1)-Cd(1)-N(1)	90.81(12)
O(5)-Cd(1)-N(1)	176.95(10)

N(2)-Cd(1)-N(1)	85.70(12)
O(3)-Cd(1)-O(2)	170.87(10)
O(1)-Cd(1)-O(2)	55.16(10)
O(5)-Cd(1)-O(2)	84.44(10)
N(2)-Cd(1)-O(2)	91.79(11)
N(1)-Cd(1)-O(2)	98.31(11)
O(3)-Cd(1)-C(1)	147.14(12)
O(1)-Cd(1)-C(1)	27.57(11)
O(5)-Cd(1)-C(1)	86.33(10)
N(2)-Cd(1)-C(1)	119.33(12)
N(1)-Cd(1)-C(1)	96.72(11)
O(2)-Cd(1)-C(1)	27.68(11)
C(1)-O(1)-Cd(1)	94.8(2)
C(1)-O(2)-Cd(1)	88.9(2)
C(5)-O(3)-Cd(1)	127.8(2)
Cd(1)-O(5)-H(5A)	109.4
Cd(1)-O(5)-H(5B)	109.3
H(5A)-O(5)-H(5B)	104.5
C(13)-N(1)-C(9)	117.2(4)
C(13)-N(1)-Cd(1)	121.4(3)
C(9)-N(1)-Cd(1)	120.8(3)
C(18)-N(2)-C(14)	116.9(4)
C(18)-N(2)-Cd(1)	122.9(3)
C(14)-N(2)-Cd(1)	119.9(3)
C(4)-N(3)-H(3A)	120
C(4)-N(3)-H(3B)	120
H(3A)-N(3)-H(3B)	120
C(8)-N(4)-H(4A)	111.4
C(8)-N(4)-H(4B)	107.2
H(4A)-N(4)-H(4B)	109.5
O(1)-C(1)-O(2)	120.8(3)
O(1)-C(1)-C(2)	119.5(3)
O(2)-C(1)-C(2)	119.7(3)

O(1)-C(1)-Cd(1)	57.64(17)
O(2)-C(1)-Cd(1)	63.47(17)
C(2)-C(1)-Cd(1)	174.0(2)
C(3)-C(2)-C(4)	119.6(3)
C(3)-C(2)-C(1)	119.2(3)
C(4)-C(2)-C(1)	121.3(3)
C(2)-C(3)-C(4)1	122.0(3)
C(2)-C(3)-H(3)	119
C(4)1-C(3)-H(3)	119
N(3)-C(4)-C(3)1	118.2(4)
N(3)-C(4)-C(2)	123.4(4)
C(3)1-C(4)-C(2)	118.4(3)
O(4)-C(5)-O(3)	125.3(3)
O(4)-C(5)-C(6)	118.5(3)
O(3)-C(5)-C(6)	116.2(3)
C(7)-C(6)-C(8)	119.3(3)
C(7)-C(6)-C(5)	120.1(3)
C(8)-C(6)-C(5)	120.6(3)
C(6)-C(7)-C(8)2	122.2(4)
C(6)-C(7)-H(7)	118.9
C(8)2-C(7)-H(7)	118.9
N(4)-C(8)-C(7)2	117.1(5)
N(4)-C(8)-C(6)	124.3(5)
C(7)2-C(8)-C(6)	118.5(4)
N(1)-C(9)-C(10)	123.2(5)
N(1)-C(9)-H(9)	118.4
C(10)-C(9)-H(9)	118.4
C(11)-C(10)-C(9)	117.8(5)
C(11)-C(10)-H(10)	121.1
C(9)-C(10)-H(10)	121.1
C(12)-C(11)-C(10)	119.6(4)
C(12)-C(11)-N(5)	115.6(4)
C(10)-C(11)-N(5)	124.8(4)

N(5)3-N(5)-C(11)	111.7(5)
C(11)-C(12)-C(13)	118.4(5)
C(11)-C(12)-H(12)	120.8
C(13)-C(12)-H(12)	120.8
N(1)-C(13)-C(12)	123.8(5)
N(1)-C(13)-H(13)	118.1
C(12)-C(13)-H(13)	118.1
N(2)-C(14)-C(15)	123.8(5)
N(2)-C(14)-H(14)	118.1
C(15)-C(14)-H(14)	118.1
C(16)-C(15)-C(14)	118.2(5)
C(16)-C(15)-H(15)	120.9
C(14)-C(15)-H(15)	120.9
C(15)-C(16)-C(17)	119.2(5)
C(15)-C(16)-N(6)	112.4(5)
C(17)-C(16)-N(6)	128.3(6)
N(6)4-N(6)-C(16)	106.5(7)
C(18)-C(17)-C(16)	118.6(6)
C(18)-C(17)-H(17)	120.7
C(16)-C(17)-H(17)	120.7
N(2)-C(18)-C(17)	123.2(5)
N(2)-C(18)-H(18)	118.4
C(17)-C(18)-H(18)	118.4

Table S3. Comparison table for different reported MOF and COF-based TENG

Sl No	Material	Mode of TENG	Voltage	Current	Reference
1	ZIF-67 /SF	CS	118 V	8 μA	[1]
2	Ni-MOF/PVDF CNF	SE	45 V	0.77 μA	[2]
3	ZIF-62/Teflon	CS	62 V	1.4 μA	[3]
4	MOF/SF@PDMS	CS	215 V	10 μA	[4]
5	MIL-88/FEP	CS	80V	2.2 μA	[5]
6	ZIF Family	CS	60 V	1.1 μA	[6]
7	ZIF-67/Teflon	CS	118 V	1.7 μA	[7]
8	F-COF/PVA	CS	177.8 V	26.34 mA m^{-2}	[8]
9	N-rich COF	CS	175V	6.3 μA	[9]
10	Cd-MOF/PDMS	CS	193.4 V	0.86 μA	This Work

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