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<i>F28F 13/00</i> (2006.01)	<i>F21V 7/00</i> (2006.01)
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(72) Inventor; and

(71) Applicant: **LEE, Choon, Sae** [US/US]; 2936 Rosedale Avenue, Dallas, TX 75205 (US).

(74) Agent: **STONE, Jack, D. Jr.**; Scheef & Stone, L.L.P., 500 N. Akard, Suite 2700, Dallas, TX 75201 (US).

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(54) Title: PASSIVE COOLING SYSTEM

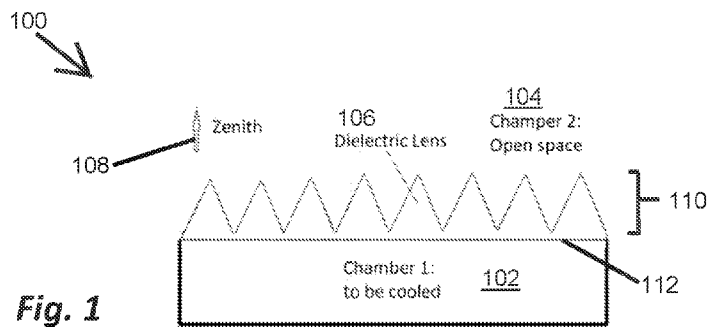


Fig. 1

(57) Abstract: Passive electromagnetic cooling is achieved using a first enclosed chamber having an antenna array surface, and a second chamber comprising open space external to the first enclosed chamber, wherein the open space comprises the sky. An interface is defined between the first chamber and the second chamber, wherein the antenna array surface is positioned with respect to the first chamber to thermally insulate between the interior of the first chamber and the open space of the second chamber. The antenna array surface is configured to direct beams from the interior of the first chamber towards the zenith of the sky. Solar irradiation in the optical spectrum range is reflected in the pyramidal dielectric surfaces or the ground plane in the dielectric rod array antenna.



## PASSIVE COOLING SYSTEM

### TECHNICAL FIELD

[0001] The invention relates generally to a system and method for passive cooling and, more particularly, to a system and method for passive electromagnetic cooling.

### BACKGROUND

[0002] The rapid growth of industrialization over the last few decades caused a significant rise in global temperatures and as a result air conditioning becomes a basic need to achieve thermal comfort for people. The World Economic Forum in May 2019 estimated that by 2050 there will be 4.5 billion air conditioners worldwide, contributing to as much as 0.5°C to the global temperature rise. There are a number of ways to make conventional AC technology more efficient such as using different refrigerants (e.g., R-32, which has less planet-warming potential than other hydrofluorocarbons). Others use technology known as “variable speed compressors” that allow the AC unit to run on different settings. Yet all past and recent efforts to control global warming and improve air conditioning efficiency cannot achieve net zero carbon emission. In short, the air-conditioning industry urgently needs technological evolution to address these challenges.

### SUMMARY

[0003] In accordance with principles of the invention, there are exemplified two radiation processes: reception and transmission to a medium which are in thermal equilibrium with the outgoing radiation. The incoming radiation from the zenith of sky is much lower than that from the horizon. The invention directs incoming radiation mainly from the zenith and suppresses that from the horizon, thus cooling the medium passively without external intervention. There is more than one way to achieve such effect. For example, various antennas, such as horn or lens antennas, can be used to direct incoming and outgoing radiation such that most incoming radiation comes from the zenith of the sky.

[0004] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be

appreciated by those skilled in the art that the conception and the specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0005] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0006] FIGURE 1 is a schematic drawing exemplifying a first embodiment of the invention, namely, a cooling system with an array of pyramidal lenses; and

[0007] FIGURE 2 is a schematic drawing exemplifying a second embodiment of the invention, namely, a dielectric antenna between the first and second chambers.

#### DETAILED DESCRIPTION

[0008] The following description is presented to enable any person skilled in the art to make and use the invention, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein. Additionally, as used herein, the term “substantially” is to be construed as a term of approximation.

[0009] The invention is an end-to-end complete passive system which can transfer heat from one region to another using electromagnetic radiation at a low cost. The operating principle is based on thermal radiation. The cooling occurs between a subject chamber to be cooled (chamber 1) and open space (chamber 2). The chambers are connected through an interface by a dielectric array antenna. For maximum cooling, there are two requirements. The first requirement is to have the beam radiated from the interface between the two chambers in a directional manner so that the radiated power from the interface is directed to the zenith of the

sky which is much colder than the earth's surface. The second requirement is to block radiation in the visual light spectrum from the open space to the interface.

**[0010]** Most conventional passive cooling systems depend on the material properties of the cooler. In contrast, according to principles of the invention, an interface between the outer chamber 2 and inner chamber 1 is altered between the area to be cooled and the open space with an antenna structure that is made of inexpensive dielectric materials.

**[0011]** Two embodiments are exemplified herein. The first embodiment (FIG. 1) uses an array of lens antennas that is easy to fabricate inexpensively at mass production scales. The second embodiment (FIG. 2) requires a more refined antenna structure for better performance.

**[0012]** In the first embodiment, designated by the reference numeral 100, FIG. 1 shows an array of dielectric lens antennas 106 at the surface of an interface 110 between a cooling chamber 102 (also referred to herein as chamber 1 or first chamber) and an open space chamber 104 (also referred to herein as chamber 2 or second chamber) wherein each array 106 element is substantially configured as a pyramid. Here the interface passes radiation from chamber 2 from substantially only near a zenith 108 of the sky away from hotter regions in the sky near the horizon so that the power entering chamber 1 from chamber 2 is minimized. The reference numeral 112 designates a ground plane.

**[0013]** The array of lens antennas 106 may be made from virtually any dielectric material; however, dielectrics with high reflection in the optical spectrum are preferred so that most solar irradiation is blocked at the interface 110. For example, a material from Rogers Cooperation (Chandler, Arizona) such as RO4003C is a type of glass that is an excellent candidate for antenna fabrication while the color of the material is mostly white which reflects most waves in the visual light spectrum. It is also suggested to put a thin layer of white paint on the dielectric surface to reflect the solar spectrum up to about 94% while transmitting the infrared waves. The key advantage of this option lies in fabrication. The size of each dielectric lens is preferably in the range of from about 0.5 mm to about 50 mm, and preferably from about 1 mm to about 10 mm, which can be easily made with currently available fabrication techniques.

**[0014]** In the second embodiment, designated by a reference numeral 200, FIG. 2 shows an array of dielectric antennas 206 at the surface of an interface 210 between a cooling chamber 202 (also referred to herein as chamber 1 or first chamber) and an open space chamber

204 (also referred to herein as chamber 2 or second chamber) where each array element is a dielectric rod 206. The interface 210 passes radiation from chamber 2 from substantially only near a zenith 208 away from hotter regions in the sky near the horizon so that the power entering chamber 1 from chamber 2 is minimized.

[0015] FIG. 2 shows a single rod 206 of an array structure (not shown) which is designed to be band-limited in the infrared wavelength band of 8-13  $\mu\text{m}$  where the atmospheric transmittivity is high, a requirement for efficient cooling. The wideband rod antenna is designed based on the leaky wave concept, which is known to give high directivity and wide bandwidth with relatively low loss. The array antenna is backed by a conducting surface 212 such as copper plate, the surface 212 also being effective as a ground plane. The dielectric structure is transparent to visible light, and most of the optical power is reflected from the conducting plate 212 since a region of aperture 214 holes (*i.e.*, holes on the ground plane 212 under each array element or rod 206) is much smaller than the entire surface area between chambers 1 and 2. In this way, the invention is operational day and night without being affected by the operation time.

[0016] Both the prior art cooling systems and the invention rely on radiative cooling based on thermal radiation. And both devices maximize the cooling with two methods: (1) steering the beam from the radiator to around the zenith 108 / 208 of sky, and (2) blocking visual light to the cooling surface. But there are fundamental differences between the two as follows:

[0017] **Beam steering:** The dielectric lens antenna in the embodiment of FIG. 1 serves the system similar to the taper guide in Zhou [*i.e.*, Zhou, L., "A polydimethylsiloxane-coated metal structure for all-day radiative cooling", *Nature Sustainability*, vol. 2, August 2019, 718-724], to steer the beam from the interface toward the zenith 108 / 208 of the sky. But there are at least two advantages of the invention over the prior art. First, the prior art structure is bulky with guide reflectors while the invention comprises a thin layer without any extra features, resulting in a compact and portable device at a low cost. Another critical disadvantage of the Zhou prior art is that the effective area for cooling is much smaller than the available space due to the presence of peripheral components, including tapered guides. In other words, the Zhou report of a cooling rate of about 120  $\text{W}/\text{m}^2$  is misleading. In practice, over an available surface for cooling, the more realistic number of Zhou is much less than the reported value. Compared to this, the invention utilizes the entire available spacing for cooling.

**[0018] Blocking visual light radiation:** Zhou places a reflecting surface, such as a conducting plate, behind the cooling panel. The serious issue here occurs when the device is used in a practical application, where one side of the cooling plate faces the open sky and the other side is backed by a conducting reflector. In other words, the heat extraction from the emitter for cooling requires a complex system that may reduce the efficiency further. On the other hand, the invention does not have any of these issues. In the invention, one side of the cooling surface is free from any obstacle for the chamber to be cooled. Compared to Rephaeli, E. et al., “Ultrabroadband photonic structures to achieve high-performance daytime radiative cooling”, *Nano Letters*, vol. 13, 2013, 1457-1461, the invention preferably does not use expensive nano-scale photonic structures (Zhou), but rather preferable inexpensive materials such as PDMS for antennas are utilized for device fabrication for comparable or even better blockage of solar irradiation.

**[0019]** In conclusion, according to the invention, the antenna at the interface between the chambers 1 and 2 is directional so that any infrared radiation from the open space will be reflected at the interface unless it is coming directly from the direction around normal to the ground surface where the equivalent temperature is about 50 K. Thus, the interface essentially works as a near ideal thermal radiator, giving a maximum heat dissipation theoretically possible in the designed bandwidth. Of course, in reality, the actual value will be lower than the ideal because there are detrimental factors such as nonideal performances of antennas, minor transmission of solar irradiation through the interface, conduction, and convection. But the cooling rate should be more than the reported rate of  $100 \text{ W/m}^2$  (Rephaeli) at a much lower cost. Compared to the prior art, the invention is relatively compact and inexpensive for commercial/residential applications.

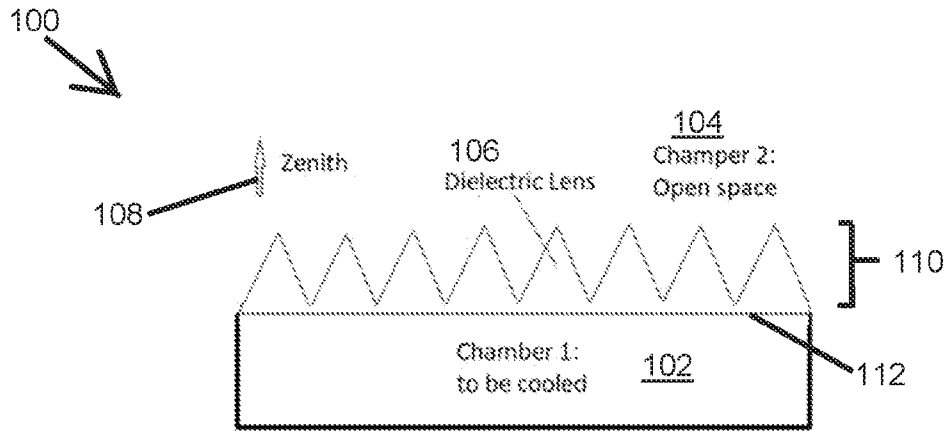
**[0020]** Having thus described the present invention by reference to certain of its preferred embodiments, it is noted that the embodiments disclosed are illustrative rather than limiting in nature and that a wide range of variations in, modifications of, changes to, and substitutions of antennas are contemplated in the foregoing disclosure and, in some instances, some features of the present invention may be employed without a corresponding use of the other features. Many such variations and modifications may be considered obvious and desirable by those skilled in the art based upon a review of the foregoing description of preferred

embodiments. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

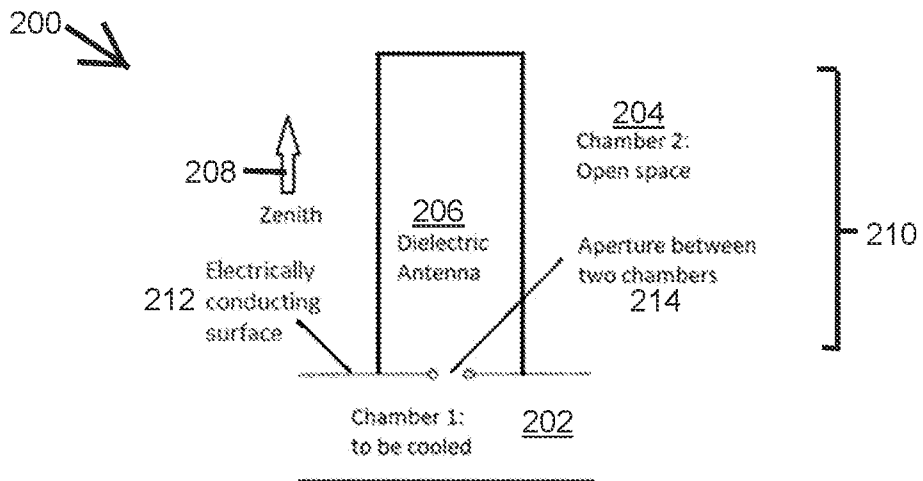
## CLAIMS

1. A system for passive electromagnetic cooling, the system comprising:
  - a first enclosed chamber having an antenna array surface;
  - a second chamber comprising open space external with respect to the first enclosed chamber, wherein the open space comprises the sky;
  - an interface defined between the first chamber and the second chamber;
  - wherein the antenna array surface is positioned with respect to the first chamber to thermally insulate between the interior of the first chamber and the open space of the second chamber; and
  - wherein the antenna array surface is configured to direct beams from the interior of the first chamber towards the zenith of the sky.
2. The system of claim 1 wherein the antenna array surface is a pyramidal lens array.
3. The system of claim 1 wherein the antenna array surface comprises an array having one or more array elements, wherein each array element is a dielectric rod antenna electrically coupled to the surface across the aperture on the ground plane and directed toward the zenith of the sky.
4. A system for passive electromagnetic cooling, the system comprising:
  - a first enclosed chamber having an electrically conductive surface;
  - a second chamber comprising open space comprising the sky;
  - an interface defined between the first chamber and the second chamber; and
  - a dielectric rod antenna electrically coupled to the electrically conductive surface across the aperture and directed toward the zenith of the sky.
5. A system for passive electromagnetic cooling, the system comprising:
  - a first enclosed chamber to be cooled;
  - a second chamber comprising open space comprising the sky; and
  - an array of pyramidal dielectric lenses arranged between the first chamber and the second chamber, wherein the lenses are directed toward the zenith of the sky.

6. A system for passive electromagnetic cooling, the system comprising:
  - a first enclosed chamber to be cooled;
  - a second chamber comprising open space comprising the sky; and
  - an array of pyramidal dielectric lenses arranged on a top side of the first chamber,wherein the lenses are directed toward the zenith of the sky and are painted with reflective material such as white colored paint.



**Fig. 1**



**Fig. 2**

## INTERNATIONAL SEARCH REPORT

International application No.

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**A. CLASSIFICATION OF SUBJECT MATTER**

**B60H 1/00**(2006.01)i; **B60H 1/32**(2006.01)i; **B82Y 20/00**(2011.01)i; **F28F 13/00**(2006.01)i; **F28F 13/08**(2006.01)i; **F28F 13/18**(2006.01)i; **F28F 3/00**(2006.01)i; **G02B 5/04**(2006.01)i; **H01L 23/36**(2006.01)i; **F21V 7/00**(2006.01)i; **F25B 27/00**(2006.01)i; **F25B 23/00**(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

B60H 1/00; B60H 1/32; B82Y 20/00; F28F 13/00; F28F 13/08; F28F 13/18; F28F 3/00; G02B 5/04; H01L 23/36; F21V 7/00; F25B 27/00; F25B 23/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Espacenet, EPOQUE Net, Scopus, IPOPHE Patent Search (WIPO Publish), Google Patents, LENS.ORG, J-PlatPat, PatentScope, Google Search, IEEE; Search Terms Used: passive, electro, magnetic, cooling, system, dielectr\*, "air condition\*", "dielectric rod", pyra\*, prism, "passive cooling", array, reflect\*, insulat\*, "dielectric rod array antenna", lens\*, photonic, Lee Choon Sae, Choon Lee, Eden Rephaeli, Passive Cooling System, dielectric lenses, electromagnetic cooling, passive electromagnetic cooling, passive cooling system for air conditioner patent, reflectors for passive cooling system

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2022/026119 A1 (LEE, Choon Sae [US]) 27 January 2022 (2022-01-27) paragraphs 0002, 0025-0026, 0029-0030, claim 18, figures 3, 5-6	1 - 6
Y	US 10,941,990 B2 (URAMAN, Aaswath Patabhi [US]; et al.) 09 March 2021 (2021-03-09) abstract, column 4 lines 6-21, column 4 lines 28-57, figures 2-4, claim 17	1 - 6
A	EP 3781891 B1 (FAIN ROMY M [US]) 10 April 2024 (2024-04-10) Whole document	1 - 6
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"D" document cited by the applicant in the international application	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

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Name and mailing address of the ISA/PH

Intellectual Property Office of the Philippines  
G/F, 2/F, 14/F, 16/F Intellectual Property Center,  
#28 Upper McKinley Road,  
McKinley Hill Town Center,  
Fort Bonifacio,  
Taguig City, 1634  
Philippines

Telephone No. (632) 7238 63 00

Facsimile No. +63288569293

Authorized officer

**Mark Darius Oribe**

Telephone No. +63 9176188895

INTERNATIONAL SEARCH REPORT

International application No.

**PCT/US2024/041983**

<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
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A	EP 3423298 A1 (UNIV COLORADO REGENTS [US]) 09 January 2019 (2019-01-09) Whole document	1 - 6

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**INTERNATIONAL SEARCH REPORT**  
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