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The effect of building integrated photovoltaic system (Bipvs) on indoor air temperatures and humidity (lath) in the tropical region of Cameroon

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Abstract

The building sector accounts for around 40-50 % of the energy consumed in developing countries and contribute over 30 % of CO_2 emissions. In Cameroon, the electricity access is less than 5 % in rural areas against 50 % in urban areas. All sectors combined the Cameroonian final energy consumption amounts to approximately 5235 kilo-tonnes of oil equivalent (Ktoe) and 73 % of this energy are assigned for residential use. This energy can be considerably reduced with the development of low energy buildings using Building Integrated Photovoltaic (BIPV), since it has been proven an effective solution to achieve significant energy savings and conservation. However, photovoltaic (PV) panels produce a substantial amount of heat, while generating power. Consequently, BIPV's concept, where the photovoltaic (PV) panel is integrated on the building envelops has significant influence on the amount of heat transfer through the building fabrics, and could affect the indoor air temperatures and the comfort of the occupants, since, it changes the thermal resistance of the building envelops. In this paper, the effect of the BIPV on the indoor air temperatures and humidity (IATH) of a multiple storey buildings under the tropical climatic conditions of Yaoundé, Cameroon has been modelled and analysed. Two cases of BIPV made of 290 m^2 area of PV have been considered, i) roof integrated and ii) façade integrated. In addition, building orientation, roof pitch and the building materials are also been explored and optimised to provide the best combination. It has been observed that for both cases, BIPV increases the building's indoor air temperature by about 4 °C, when compare to a building of the same size without PV integrated.

Keywords: Building Integrated Photovoltaic (BIPV); Passive design; Heat transfer; Energy conservation; Thermal comfort; Solar energy

Introduction

Whatever the building to build or manage, solutions to control energy consumption must be sought. This is true in the world for all types of buildings, industrial, commercial or residential. Before designing or improving a building, it is essential to study its energy needs and energy sources available, and then look for the best adequacy of management systems, distribution networks and consumer equipment taking into account operating requirements.

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Energy demand

The power industry emissions were 10.9 giga-tonnes of carbon dioxide equivalents (GtCO2e) per year in 2005, i.e. 24 % of global Greenhouse Gas (GHG) emissions, and this is expected to increase to 18.7 GtCO2e per year in 2030 (Jelle et al. 2012). The world population is estimated at 8.2 billion people for an energy consumption of15.3 billion-tone oil equivalent (toe) in 2030 (International Energy Agency (IEA) 2012). There is a statistically relation between population and economic growth, energy use, and CO_2 emissions (Mohd Shahidan et al. 2013). The population growth increase energy use. An important part of this energy is use in the building sector, that represent about 40-50 % of the energy consumed in developing countries and will be responsible nearly 4300 toe of CO_2 emissions for these country in 2030 (International Energy Agency (IEA) 2012). In Cameroon, the energy demand still remains unsatisfied and the access to modern energy is very low, in the national average range of 15 % for electricity and 18 % for domestic gas. In addition, the electricity access is less than 5 % in rural areas against 50 % in urban areas. All sectors combined, the Cameroonian final energy consumption amounts to approximately 5235 Ktoe in 2006 (SIE-Cam; AES-Sonel; CSPH, Nkutchet, 04).

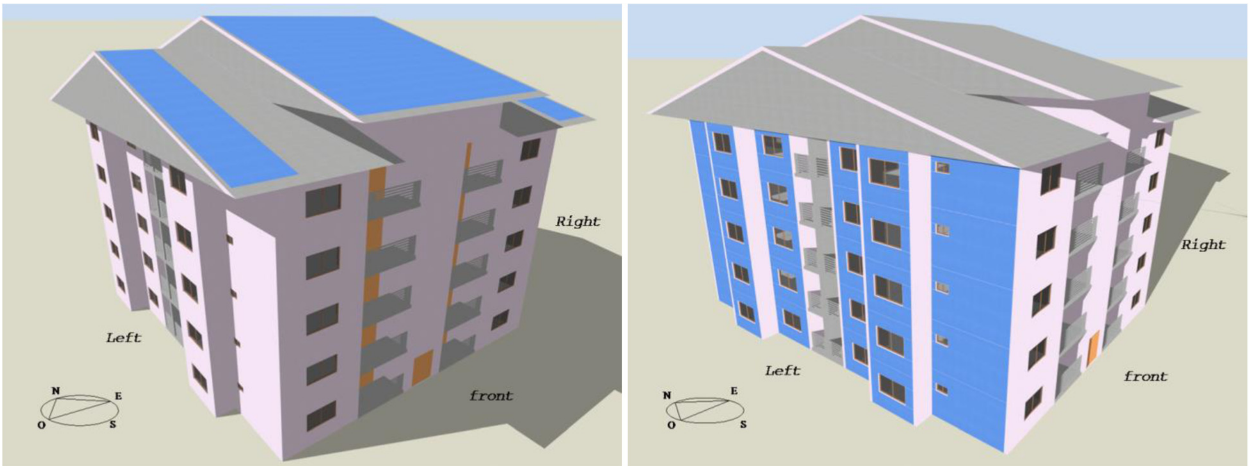
Tropical building low energy

Energy is used for the building comfort that means cooling in tropical region. The construction of low energy buildings is an effective solution that achieves significant energy savings. Low-energy buildings use passive techniques, such as optimal solar gain, and advanced active systems, such as mechanical ventilation with heat recovery, to create comfortable internal environments that have low energy demand. Renewable heating systems including biomass boilers, active solar water heating and ground source heat pumps can be used to supply heating and hot water needs with reduced gas emissions. Solar photovoltaic can be used to provide electricity. Solar energy systems can play an important role in reducing building energy consumption (Hestnes 1999) in tropical region because of it abundance.

The building integrated photovoltaic

Building integrated photovoltaic (BIPV): The concept where the photovoltaic element assumes the function of power generation and the role of the covering component element has significant influence on the heat transfer through the building envelope. Kimura (Kimura 1994), Taleb and Pitts (Taleb & Pitts 2009), and (Zhai et al. 2008) have illustrated various methods of installing the PV modules into a building for a concept of green building. In modern buildings, windows play an important role in energy performance with respect to heating/cooling loads and artificial lighting requirements. The relationship between window design and building energy performance has been extensively researched (Stegou-Sagia et al. 2007; Iqbal & Al-Homoud 2007; Lee & Selkowitz 2006; Wong et al. 2005; Bodart & De Herde 2002; Zain-ahmed et al. 2002; Mehlika et al. 2000; Al-Homoud 1997). Ciampi et al. (Ciampi et al. 2003) show that carefully designed ventilated facades, walls and roofs can reduce considerably the summer thermal loads.

The advantage of integrated photovoltaic over non-integrated systems is the reduction of construction costs of building materials. These advantages make BIPV one of the fastest growing segments of the photovoltaic industry (Park et al. 2010). For BIPV systems to achieve multifunctional roles, various factors must be taken into account, such as the photovoltaic module temperature, shading, installation angle and orientation, effect integration on building thermal comfort (Peng et al. 2011). Infield et al. (Infield et al. 2004) applied a steady state analysis model in a ventilated PV facade in order to evaluate an overall heat loss coefficient and thermal gain factor and suggested that the temperature of the PV module can be reduced by flowing air between the PV module and the double glass wall. Similar studies were carried out by (Tripanagnostopoulos et al. 2002), (Zondag et al. 2002), (Prakash 1994) and (Chow et al. 2003) by flowing air and water below the PV module to increase the electrical efficiency of the PV module. (Tiwari et al. 2006) have evaluated the performance of the photovoltaic (PV) module integrated with air duct for composite climate of India. Analytical expression for overall energy efficiency (electrical and thermal) has been derived. It is observed that there is a fair agreement between theoretical and experimental observations and concluded that an overall energy efficiency of photovoltaic thermal (PVT) system is significantly increased by utilization of thermal energy in PV module. (Agrawal & Tiwari 2010) optimized the opaque type BIPVT system for cold climatic conditions. The system fitted on the roof top of Srinagar over an effective area of 65 m^2 produces annually the electrical and thermal exergy of 16209 kWh and 1531 kWh. (Vats & Tiwari 2012) evaluate a building integrated semitransparent photovoltaic thermal (BISPVT) system and found for an effective area of 5.44 m^2 overall annual thermal energy gain is 2497 kWh and electrical gain is 810 kWh. (Ekoe et al. 2015) proposed a thermal modelling of a semi-transparent PV module with fins at the back surface. It is observed that the system exhibits higher thermal and electrical efficiencies than the conventional BISPVT systems, the maximum value of cell temperature can decreased from 62.68 °C to 53.75 °C and heat extracted by air in a year from the fin surface is amounts 55.4 kWh/year. The results of basic studies on irradiance and energy output of photovoltaic systems have been reported by some researchers (Rahman et al. 1988; Celik 2003; Smiley 2001) while there have been other studies on the temperature and generation performance of photovoltaic modules (Mattei et al. 2006;



(a) (b)

Fig. 1 BIPV integration on roof top (**a**) and on façade (**b**)

Carr & Pryor 2004; Chenni et al. 2007) integrated in building.

Building indoor air condition

The humidity is among the indoor environmental factors that could affect thermal comfort in a building. Accurate prediction of indoor conditions, specifically indoor temperature and relative humidity, are important for the following four reasons: 1) To better assess the hygrothermal performance of building envelope components (Tsongas et al. 1996; Tariku et al. 2009) and reduce the likelihood of building envelope failure. High indoor humidity can result in excess moisture accumulation in the structures and deterioration of components due to mold/decay or corrosion. 2) To maintain the critical relative humidity range, which is specific to the building's operation (Trechsel 2001; Rode 2003). The relation between relative humidity of air and indoor air temperature was developed by Djamila in the Malaysia climate environment for indoor temperature range of 27 °C to 35 °C (Djamila et al. 2014). Hartwig summarizes the findings concerning indoor relative humidity, and specifications, which are partly derived from standards or guidelines for the hygrothermal design of building components Hartwig et al.

When solar photovoltaic system is integrated in building, indoor air temperature and humidity (IATH) are changed due to the modification of thermal resistance of building envelope. There are not many research focused on that ways. In this paper, the effect of the BIPV on the indoor air temperatures and humidity (IATH) of a multiple storey buildings under the tropical climatic conditions of Yaoundé, Cameroon has been modelled and analysed. Two cases of BIPV made of 290 m^2 area of PV have been considered, i) roof integrated and ii) façade integrated. In addition, building orientation, roof pitch and the building materials are

Table 1 Buildings materials properties

		e	*U*
Roof	Aluminum sheet	0.001	7.143
	Plywood	0.004	3.371
Wall	Cast concrete/Concrete block/ Cast concrete	0.015 + 0.17 + 0.015	0.833
	Cast concrete/breeze bloc/ Cast concrete	0.015 + 0.17 + 0.015	2.450
	Cast concrete/brickwork/ cast concrete	0.015 + 0.17 + 0.015	2.507
	Cast concrete/Ashlar stone/ Cast concrete	0.015 + 0.17 + 0.015	3.643
	Woods	0.2	0.626
	Rammed earth, (adobe)	0.2	3.065
Openings	Wooden door	0.03	2.393
	Glass Window	0.01	3.571

Table 2 Design parameters of BIPV facade integration

		e	*U*
On wall	PV module	0.01	3.571
	Concrete block	0.015	4.774
	Glass/insulation	0.004	3.226

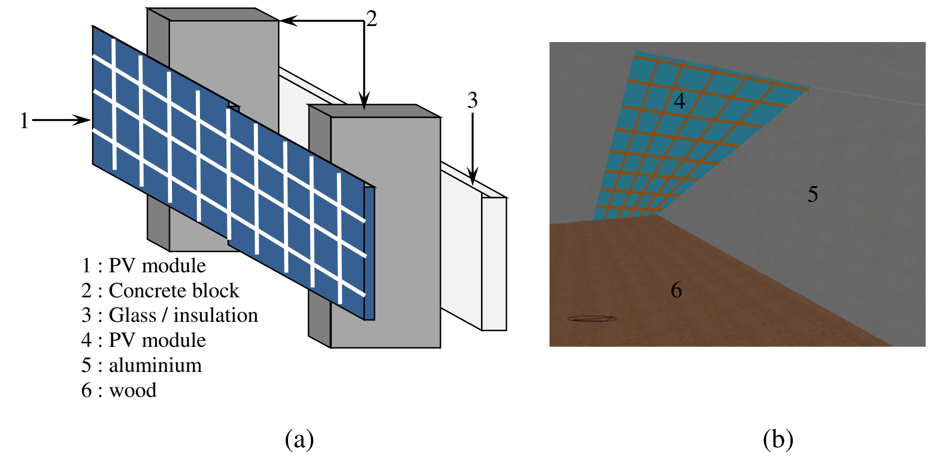


Fig. 2 Building integrated photovoltaic system (**a**) at facade and (**b**) at roof

also been explored and optimised to provide the best combination.

Problem identification

The building in Yaoundé, Cameroon situated at 3°852' N, 10°83' E is under consideration. The size of the building is 26.65 m × 22.6 m with an average height of 15.3 m. The building is insulated by the layer of sand and cement. The roof top cover an effective area of (375.8 × 02) m^2 and an effective area on façade are respectively 348.15 m^2 on the top side and behind, 396.15 m^2 on the right and the left side. Photovoltaic system is integrated on the roof or at facade. Figure 1 shows the pictorial view of building and the BIPV system. The choice of roof inclination and building orientation are derived from overall building air temperature calculation.

Thermal analysis

Thermal resistance

The heat flow through a building construction depends on the temperature difference across it, the conductivity of the materials used and the thickness of the materials. The temperature difference is an external factor. The thickness and the conductivity are properties of the material. These parameters form the thermal resistance of the construction, given as:

$$R = \frac{e}{k\,S} \qquad (1)$$

The total resistance of an element includes all of the resistances of the individual materials that make it up as well as both the internal and external air-film resistance. According to the material used, theirs dimensions and theirs thermal properties, each part of building envelop will have its own overall heat transfer coefficient.

Relative humidity

Relative humidity indoors has a very important role in respect of indoor air quality, thermal comfort, occupant health, material emissions and energy consumption. A too low relative humidity indoors may cause respiratory illnesses and asthma. However, also too high relative humidity has negative effects such as mould and moisture problems, dust mites and it might also cause respiratory illnesses (Airaksinen 2013). The following formula gives the Relative Humidity (Morel & Gnansounou 2009):

$$RH = 100\ \%\frac{P_v}{P_{ws}(T_d)} = 100\ \%\frac{P_{ws}(T_d)}{P_{ws}(T_{indoor})} \qquad (2)$$

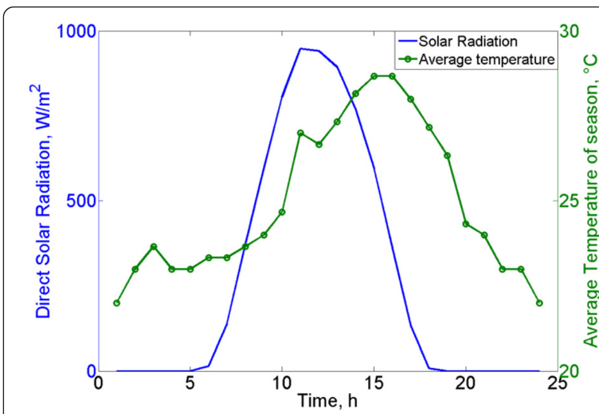


Fig. 3 Average solar radiation and ambient temperature

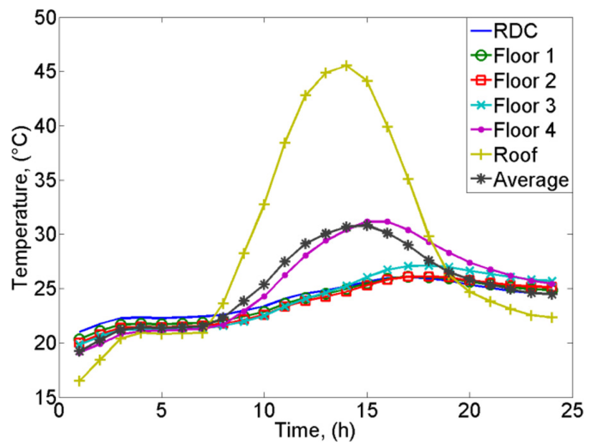


Fig. 4 Building indoor air temperatures without BIPV installed

Where T_d the dew point temperature of vapor water is given as:

$$T_d = \frac{237.3\ \ln\left(\frac{P_v}{610.5}\right)}{17.27-\ln\left(\frac{P_v}{610.5}\right)} \qquad if\ P_v \geq 610.5\,Pa$$
$$T_d = \frac{273\ \ln\left(\frac{P_v}{610.5}\right)}{22.5-\ln\left(\frac{P_v}{610.5}\right)} \qquad if\ P_v \leq 610.5\,Pa \tag{3}$$

The water vapour saturation pressure to sufficient accuracy between 0 °C and 373 °C is given as (Wagner & Pruß 2002):

$$\ln\left(\frac{P_{ws}}{P_c}\right) = \frac{T_c}{T}\left[\begin{array}{l} C_1\left(1-\frac{T}{T_c}\right) + C_2\left(1-\frac{T}{T_c}\right)^{1.5} + C_3\left(1-\frac{T}{T_c}\right)^3 \\ +C_4\left(1-\frac{T}{T_c}\right)^{3.5} + C_5\left(1-\frac{T}{T_c}\right)^4 + C_6\left(1-\frac{T}{T_c}\right)^{7.5} \end{array}\right] \tag{4}$$

Methodologies

For the evaluation of the influence of the changes in the thermal resistance of the building envelope on the temperature of the internal air of the building, the following steps are considered:

- The physical model of the building has no internal heat source and no activity is considered
- Daylight and natural ventilation are only considered
- The building physical model has no HVAC system
- The properties of air is constant with temperature

The average temperature of the building and its different floors are determined for the building without BIPV integration.

BIPV on facade

The BIPV system is integrated on facade, and the average hourly temperature variation of the building is determined, as well as different floors of the building. This is made for different rotations of 90° to the front side corresponding to the North, East, South and West orientation. For the orientation corresponding to the maximum and minimum temperature obtained, the type of main walls of the building material is modified by those embedded in the customs of local buildings in Cameroon.

BIPV on the roof top

BIPV system is integrated in the roof, and the average hourly temperature variation of the building is determined, as well as the different floors of the building. This is made for different rotations of 90° to the front side corresponding to the North, East, South and West orientation. For the orientation corresponding to the maximum and minimum temperatures, calculations are also performed for an inclination of the roof from 5° to

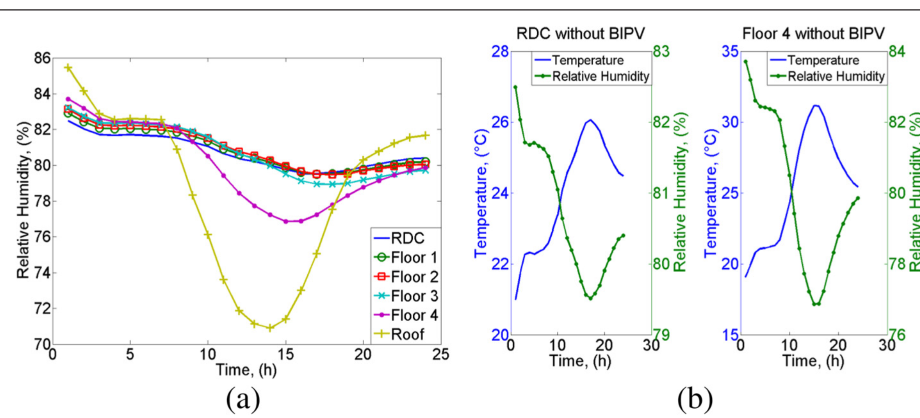


Fig. 5 Indoor air relative humidity (**a**) and its comparison with temperature (**b**)

40°, then the nature of the main roof material is changed.

The relative humidity is obtained with the help of Eq. (2, 3, 4).

The simulation is performed with the Designbuilder software that integrates the powerful calculation tool energyplus.

Input parameter for building model

Weather data

In order to obtain the dynamic behaviour of the system, as well as estimating the internal building air temperature for hot season of the year, we used global and diffuse solar radiation data of a representative day over Yaoundé region for the year 2012 obtained from the Energy and Environmental Technologies Laboratory of the Department of Physics at the University of Yaoundé I; we also used climatic data issued by the Atmospheric Physics Laboratory.

Thermal properties of building materials

Table 1 summarises the properties of building materials. The overall heat transfer coefficient U calculated with energyplus convection algorithm take account

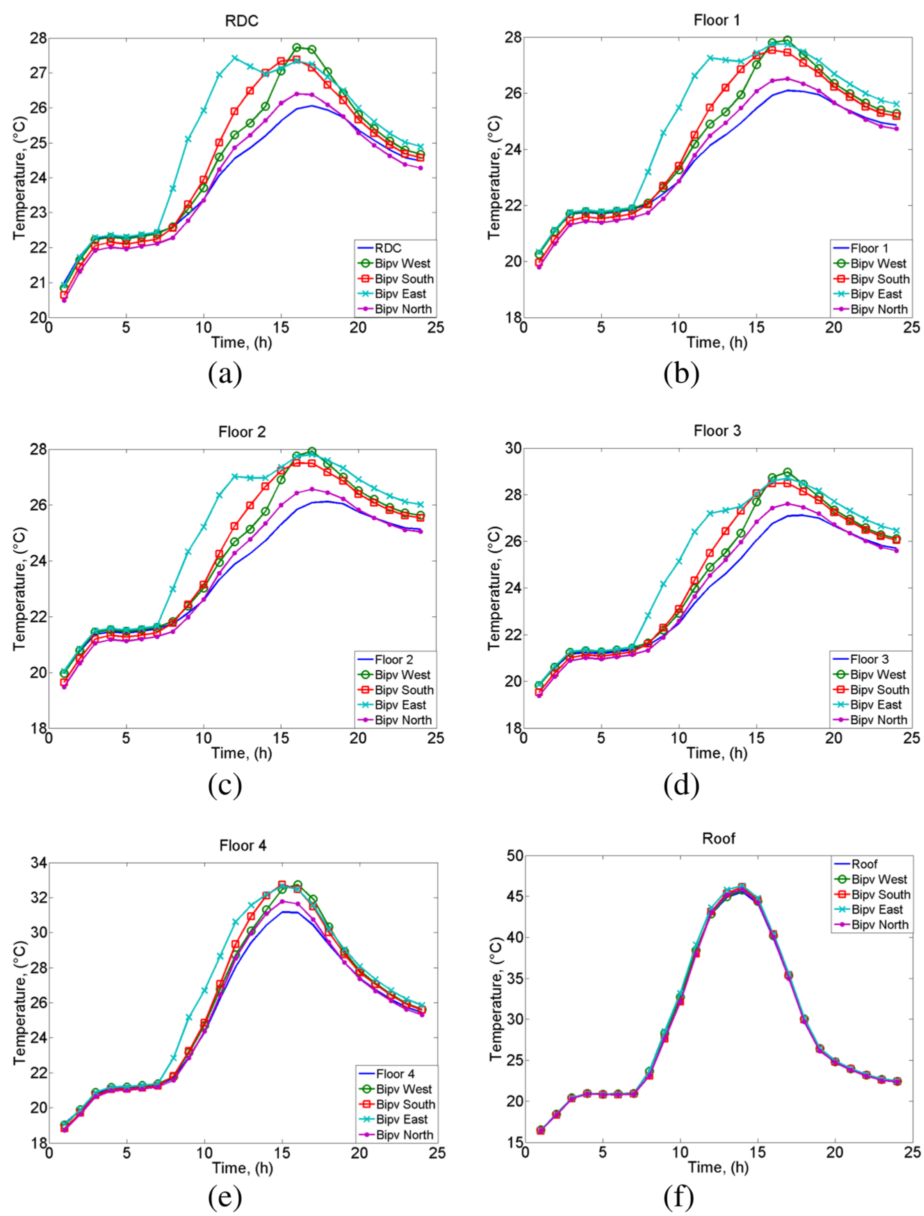


Fig. 6 Hourly temperature variation of indoor air of the main floor building (**a**), floor 1 to 4 (**b**) – (**e**) and roof (**f**) for BIPV facade integration with building orientation

the convective heat transfer coefficient of internal and external surface (2.152, 19.87) W/m^{2}K and the radiative heat transfer coefficient of internal and external surface (5.54, 5.13) W/m^{2}K.

BIPV system

The values of the design parameters of BIPV facade integration are given in Table 2 and Fig. 2 shows the pictorial view of building integrated photovoltaic system.

Result and discussion

The variations of global and diffuse solar radiation data of Yaoundé for the year 2012 obtained from the Environmental Energy Technologies Laboratory (EETL) at the University of Yaoundé I and the average temperature are shown in Fig. 3.

The main floor building (RDC), floor 1 to 4, roof and average building hourly temperature are shown in Fig. 4.

It is observed that the air temperature inside the building increases with the floor level. The indoor air temperature of the main floor building and floor 1 to 3 is substantially equal to the outside air temperature. However, from the fourth floor, indoor air temperature of the building is higher than the outside temperature, from 9:00 am to 11:00 pm with a maximum temperature difference of 3 °C à 06:00 pm.

It is observed from the Fig. 5 that the relative humidity of indoor air of buildings varied between 70.89 % and 85.45 %. The indoor relative humidity decrease when the temperature of air inside the building increases. A temperature difference of 2 °C corresponds to a relative humidity difference of 1 %. The variation of hourly air temperature of the main floor building, floor 1 to 4 and roof for facade bipv integration are presented in Fig. 6.

The integration of PV modules in the structure of the building envelope modified the indoor air temperature of the building, with a maximum temperature difference of 3.15 °C observed at 12:00 am. It is also observed that this integration has a negligible effect on the indoor air temperature of the roof.

The level of natural ventilation in a building depends on the direction and the speed of the wind, the orientation of the construction and its opening. Natural ventilation also influence the temperature of the indoor air of the building by renewing the indoor air with an almost constant and regular flow rate. This attenuation is maximal when the openings create a horizontal flow of air.

The maximum temperatures differences induced by this type of integration are observed on the floor 3 when the BIPV area is oriented East side, while the minimum temperatures are obtained with BIPV is North orientated. Figure 7 shows the hourly temperature of floor 3 for different types of the principal wall materials.

By a combination of the orientation with the type of the principal wall material, temperature difference can be up to 4 °C obtained with the wood as the main material of the wall.

The variation of hourly temperatures of the main floor building, floor 1 to 4 and roof for BIPV roof integration with building orientation are presented in Fig. 8.

The integration of photovoltaic modules on the roof of the building modified the indoor air temperature of the roof and the floor on which it is based, namely the 4th floor, with a maximum temperature difference of 2.7 °C at 12:00 am. The temperature is maximum when the PV system is oriented south, while the west orientation provides minimum temperatures for roof integration.

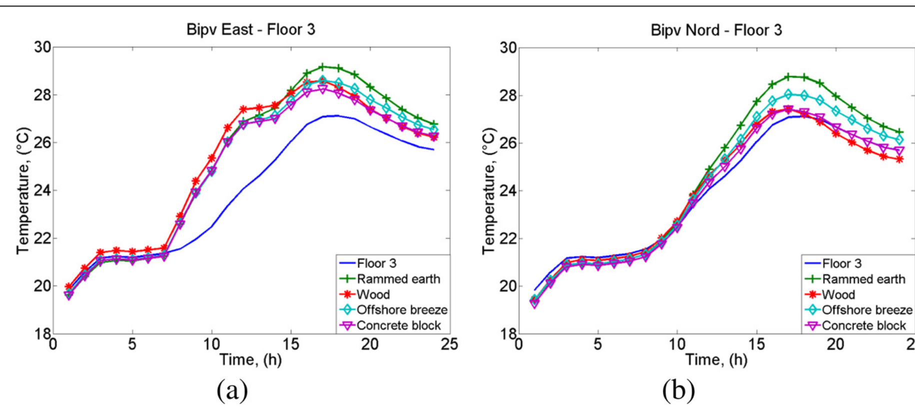


Fig. 7 Hourly temperature variation of indoor air of floor 3 for different type of the principal wall material for bipv East orientation (**a**) and bipv Nord orientation (**b**)

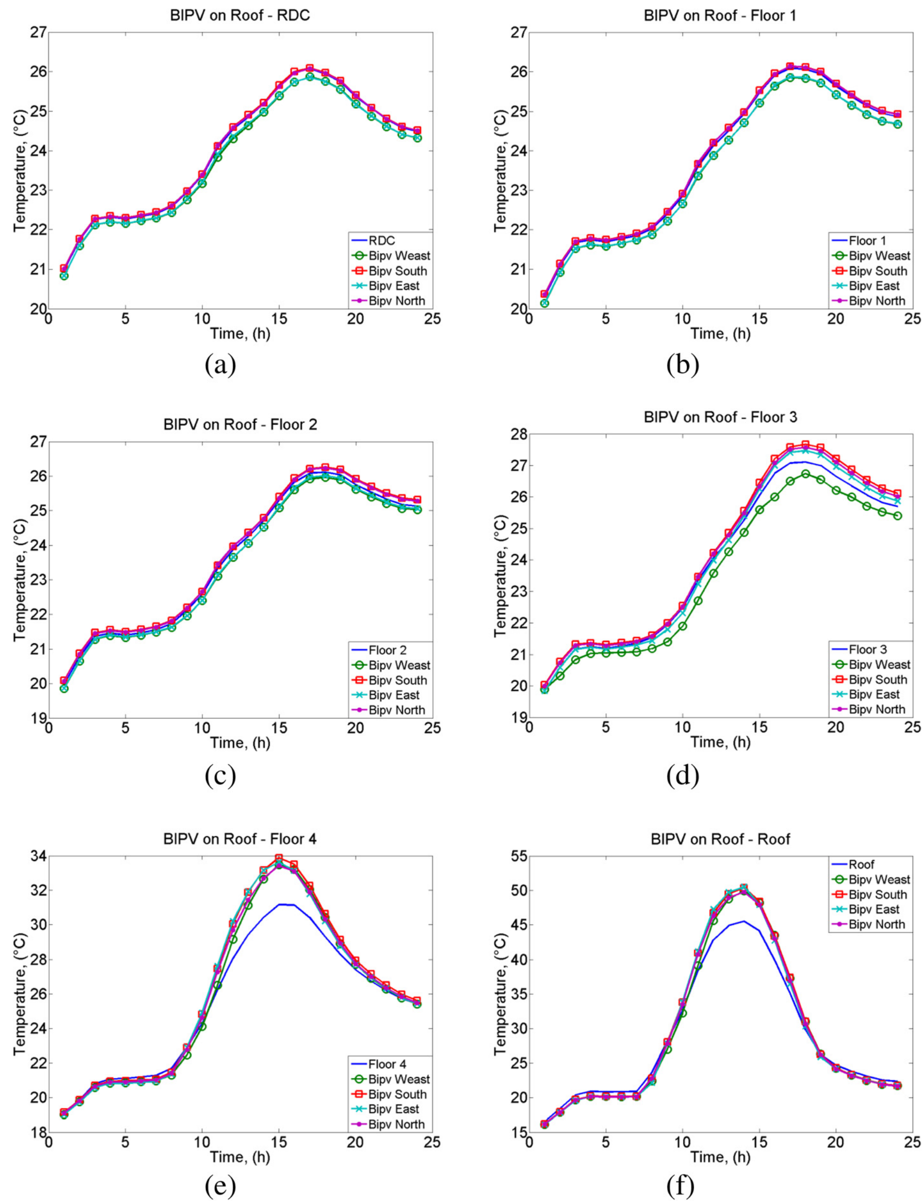


Fig. 8 Hourly temperature variation of indoor air of the main floor of building (**a**), floor 1 to 4 (**b**) – (**e**) and roof (**f**) for BIPV roof integration with building orientation

Figure 9 shows the hourly variation of the internal temperature on the floor 4 with roof inclination of 5° to 40° for the southern and western orientation.

A comparison between the two types of BIPV integration is made through Fig. 10 which shows the variation of the average hourly indoor air temperature of the building.

It is observed that the BIPV roof integration is more advantageous than the BIPV façade integration:

- It offers more exploitable area
- It has an influence on the indoor air temperature of the building more than that induced by the BIPV façade integration when the roof temperature is included.

Conclusions

The influence of a building integrated photovoltaic system (BIPV) on room air temperature in tropical region has been analysed. The comparison of room air temperature derived from roof integration and façade integration is made for the same area in residential buildings, orientation

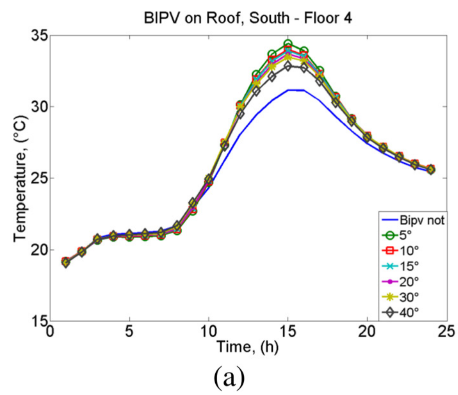


Fig. 9 hourly temperature variation of indoor air of building floor 4 with roof inclination for south (**a**) and west (**b**) orientation

of buildings, roof inclination and building materials are also explored. It has been observed that:

- BIPV increases the building indoor air temperature
- The indoor relative humidity decrease when the temperature of air inside the building increases. A temperature difference of 2 °C corresponds to a relative humidity difference of 1 %.
- The temperature difference of indoor air temperature of building with BIPV and without can reach to 4° by combining orientation of building and the building material envelope
- The effect of roof integration on the indoor air temperature and humidity (IATH) of the building is more than that induced by the Bipv façade integration.

The principal parameter of BIPV is building orientation, the increase of building indoor air temperature due to BIPV façade integration can be considerably reduced by the openings if they create a horizontal flow of air.

Nomenclature

e Thickness (m)
RH Relative Humidity (%)
k Thermal conductivity (W/m·K)
P Pressure, (hPa)
R Thermal resistivity (K/W)
S Area (m^2)
T Temperature (K)
U Overall heat transfer coefficient (W/m^2K)
Greek symbols
ϕ Inclination of roof (rad)
Subscripts
BIPV Building Integrated Photovoltaic System
C Critical, constant
d Direct, Dew point
IATH Indoor Air Temperature and Humidity
HVAC Heating, ventilating and air Conditioning
g Global
RDC main floor of building, ground floor
v vapor Water
ws Water vapour saturation

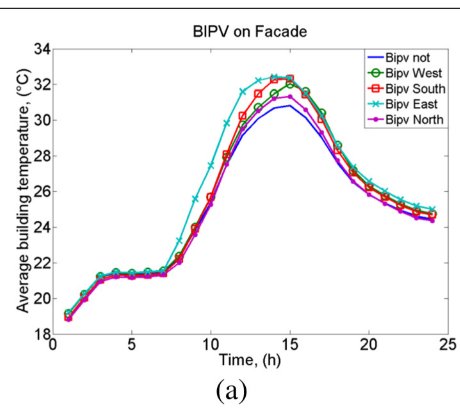


Fig. 10 Average hourly indoor air temperature of the building for BIPV facade (**a**) and roof (**b**) integration

Appendix A: Equation (4) constant

$C_1 = -7.85951783$
$C_2 = 1.84408259$
$C_3 = -11.7866497$
$C_4 = 22.6807411$
$C_5 = -15.9618719$
$C_6 = 1.80122502$
$Pc = 220640$ hPa
$Tc = 647.096$ K

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
Ekoe and Njomo have analyzed and modeled the building integrated PV in the tropical region of Cameroun and Ekoe simulated the physical model of the building. Ekoe and Mempouo have determined the air quality in the building (the properties of air). Ekoe, Njomo and Mempouo have drafted the manuscript. All authors read and approved the final manuscript.

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References

Agrawal B, Tiwari GN (2010) Optimizing the energy and exergy of building integrated photovoltaic thermal (BIPVT) systems under cold climatic conditions. Appl Energy 87:417–426
Airaksinen M (2013) The Influence of Moisture Capacity of Building Materials on the Indoor Air Quality. Int J Environ Prot 3(7):1–10
Al-Homoud MS (1997) Thermal design of office buildings. Int J Energy Res 21(10):941–957
Bodart M, De Herde A (2002) Global energy savings in offices buildings by the use of day lighting. Energy Build 34(5):421–429
Carr AJ, Pryor TL (2004) A comparison of the performance of different PV module types in temperate climates. Sol Energy 76:285–294
Celik AN (2003) Long-term energy output estimation for photovoltaic energy systems using synthetic solar irradiation data. Energy 28(5):479–493
Chenni R, Makhlouf M, Kerbache T, Bouzid A (2007) A detailed modeling method for photovoltaic cells. Energy 32(9):1724–1730
Chow TT, Hand JW, Strachan PA (2003) Building-integrated photovoltaic and thermal applications in a subtropical hotel building. Appl Therm Eng 23:2035–2049
Ciampi M, Leccese F, Tuoni G (2003) Ventilated facades energy performance in summer cooling of buildings. Sol Energy 75:491–502
Djamila H, Chu C-M, Kumaresan S (2014) Effect of Humidity on Thermal Comfort in the Humid Tropics. J Build Construction Plann Res 2:109–117
Ekoe A Akata AM, Njomo D, Agrawal B (2015) Thermal energy optimization of building integrated semi-transparent photovoltaic thermal systems. Int. J Renew Energy Dev 4(2):113–123. dx.doi.org/10.14710/ijred.4.2.113-123
Hartwig M. Künzel. Indoor Relative Humidity in Residential Buildings – A Necessary Boundary Condition to Assess the Moisture Performance of Building Envelope Systems. Download: http://www.hoki.ibp.fraunhofer.de/ibp/publikationen/fachzeitschriften/wksb%20Raumluftfeuchte1_E.pdf
Hestnes AG (1999) Building Integration of Solar Energy Systems. Sol Energy 67:181–187
Infield D, Mei L, Eicker U (2004) Thermal performance estimation for ventilated PV facades. Sol Energy 76:93–98
InternationalEnergy Agency(IEA) (2012) World energy outlook
Iqbal I, Al-Homoud MS (2007) Parametric analysis of alternative energy conserva-tion measures in an office building in hot and humid climate. Build Environ 42(5):2166–2177
Jelle BP, Breivik C, Røkenes HD (2012) Building integrated Photovoltaicproducts: astate-of-the-art review and future research opportunities. Sol Energy Mater Sol Cells 100:69–96
Kimura K-i (1994) Photovoltaic systems and architecture. Sol Energy Mater Sol Cells 35:409–419
Lee SE, Selkowitz ES (2006) The New York Times headquarters day lighting mockup: monitored performance of the day lighting control system. Energy Build 38(7):914–929
Mattei M, Notton G, Cristofari C, Muselli M, Poggi P (2006) Calculation of the polycrystalline PV module temperature using a simple method of energy balance. Renew Energy 31:553–567
Mehlika N, Inanici F, Nur D (2000) Thermal performance optimisation of buildingaspect ratio and south window size in five cities having different climaticcharacteristics of Turkey. Build Environ 35(1):41–52
Mohd Shahidan Shaari, Hafizah Abdul Rahim, Intan Maizura Abd Rashid (2013) Relationship among population, energy consumption and economic growth in malaysia. Int J Soc Sci. Vol. 13, No. 1
Morel N, Gnansounou E (2009) Energétique du Bâtiment
Park KE, Kang GH, Kim HI, Yu GJ, Kim JT (2010) Analysis of thermal and electrical performance of semi-transparent photovoltaic (PV) module. Energy 35:2681–2687
Peng C, Huang Y, Wu Z (2011) Building - integrated photovoltaics (BIPV) in architectural design in china. Energy Build 43:3592–3598
Prakash J (1994) Transient analysis of a photovoltaic-thermal solar collector for co-generation of electricity and hot air/water. Energy Convers Manag 35:967–972
Rahman S, Khallat MA, Salameh ZM (1988) Characterization of insolation data for use in photovoltaic system analysis models. Energy 13(1):63–72
Rode C (2003) Whole Building Hygrothermal Simulation Model. ASHRAE Transactions
Smiley EW (2001) Low irradiance performance modelling for building integrated photovoltaics. In: 17th European PV Solar Energy Conference, Munich, Germany
Stegou-Sagia A, Antonopoulos C, Angelopoulou C, Kotsiovelos G (2007) The impact of glazing on energy consumption and comfort. Energy Convers Manag 48(11):2844–2852
Taleb HM, Pitts AC (2009) The potential to exploit use of building-integrated photovoltaics in countries of the Gulf Cooperation Council. Renew Energy 34:1092–1099
Tariku F, Kumaran MK, Fazio P (2009) The need for an accurate indoor humidity model for building envelope performance analysis, 4th International Building Physics Conference, Istanbul, Turkey
Tiwari A, Sodha MS, Chandra A, Joshi JC (2006) Performance evaluation of photovoltaic thermal solar air collector for composite climate of India. Sol Energy Mater Sol Cell 90:175–189
Trechsel HR (2001) Moisture Primer, Moisture Analysis and Condensation Control in Building Envelopes, ASTM Manual series 50: Chapter 1
Tripanagnostopoulos Y, Nousia T, Souliotis M, Yianoulis P (2002) Hybrid photovoltaic/thermal solar systems. Sol Energy 72:217–234
Tsongas, G. Burch, D. Roos, C. Cunningham, M. (1996). A Parametric Study of Wall Moisture Contents Using a Revised Variable Indoor Relative Humidity Version of the 52 MOIST Transient Heat and Moisture Transfer Model. Proceedings of the Thermal Performance of Exterior Envelopes VI Conference, Dec. 4–8, Clearwater Beach, FL
Vats K, Tiwari GN (2012) Energy and exergy analysis of a building integrated semitransparent photovoltaic thermal (BISPVT) system. Appl Energy 96:409–416
Wagner W, Pruß A (2002) The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use. J Phys Chem Ref Data 31(2):387535
Wong NH, Wang L, Chandra AN, Pandey AR, Wei X (2005) Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore. Energy Build 37(6):563–572
Zain-ahmed A, Sopian K, Othman MYH, Sayigh AAM, Surendran PN (2002) Day lighting as a passive solar design strategy in tropical buildings: a case study of Malaysia. Energy Convers Manag 43(13):1725–1736
Zhai XQ, Wang RZ, Dai YJ, Wu JY, Ma Q (2008) Experience on integration of solar thermal technologies with green buildings. Renew Energy 33:1904–1910
Zondag HA, de Vries DW, van Helden WGJ, van Zolingen RJC, van Steenhoven AA (2002) The thermal and electrical yield of a PV-thermal collector. Sol Energy 72:113–128