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A study on outdoor environment and climate change effects in Madagascar

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A B S T R A C T

The warming of the planet is a big threat to humanity. The consequences vary depending on the geographical position of each country. Anthropogenic activities continue to emit potential greenhouse gases (GHG) into the atmosphere leading to a warmer climate. According to the World Meteorological Organization, Madagascar Island is one of the world's most vulnerable regions on earth. This research aims to study the variation in outdoor climate in some regions of Madagascar and also to assess the global warming impact on energy demands in 16 regions in Madagascar. A meticulous analysis of the current pressure of environment on human health has been completed. Several general circulation models (GCMs) (BCCRBCM2, INMCM-30, NCARPCM1) have been combined with several scenarios (A2 and A1B) to screen the Climate Change outside, as also to assess the state of comfort in the surrounding environment. Finally, we have used the General Circulation Model (INCM3) combined with scenario A2 for forecasting. The results show that an average increase of 0.6°C will be observed after 25 years in all regions of Madagascar. The heating degree will see an increase of 7% per decade in the cities nearest the sea. Between June and September, the energy demand is very low, but from October, this energy demand increases very fast, to reach up to 4.8KJ/Kg in December. In humid tropical climate regions, it has been found that the environment will be more uncomfortable, because the humidex value will increase up to 40 in the next decade.

Keywords: Outdoor, environment, climate change, Madagascar

1. Introduction

Man, thanks to his intelligence, acted on the environment to improve his lifestyle. This human action on the environment has improved the lives of billions of people, but it has also changed the nature of the ecosystem. The global climate system is an integral part of all processes necessary to sustain life. In many parts of the globe, a sudden change in climate, with a high degree of heating has been observed from 1950. The consequences of global warming are many and vary from region to region (IPPC, 2007; IPPC, 2001; Zhang *et al.*, 2007; Webster *et al.*, 2005; Tadross *et al.*, 2005). The consequences of this phenomenon have stayed positive in some countries of Asia and America, but in a majority of the cases, they are negative. The climate has always had a powerful impact on the health and well-being of humans. Changes in rainfall are typically harder to detect (Rabefitia *et al.*, 2008; Tadross *et al.*, 2008). The causes of climate change may be natural, but they are also man-made (IPCC, 2007). The sectors related to transport, industry, agriculture and building, discharge more than 80% CO2 into the atmosphere (IEA, 2010; Goldemberg, 2000). The transition between renewable and fossil energy is extremely slow, despite several state summits summoned for this purpose (Roshan *et al.*, 2012; Delfani *et al.*, 2010). Several recent disasters have shown that there has been insufficient preparation in this area (Onerc, 2007). According to some scientists, heat waves will become more frequent and more intense (IPCC, 2007b; Jetten *et al.*, 1997; Joussaume *et al.*, 2006; Lacaux, 2006). Storms, tropical cyclones and their aftermath represent a second type of threat (Lacaux *et al.*, 2007; Laaidi *et al.*, 2006). During the twentieth century, the global average surface temperature has increased by about

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0.6°C, and about two-thirds of this increase has occurred since 1975 (Watson *et al.*, 1998; IPPC, 2007b). However, in the twenty-first century, many impacts on natural systems are expected(IPPC,2007). In case of significant warming, the capacity of ecosystems to adapt will be exceeded, resulting in adverse effects such as increased risk of extinction of species. Besides changes in temperature and rainfall, other aspects of global change are notable. To make sound decisions, policy makers need useful and timely information about the possible consequences of climate change. Delaying emission reduction measures, limits the ability to achieve low stabilisation levels and increases the risk of serious impacts of climate change (IPPC, 2001). The study of Seguin *et al.* (Seguin, 2002) confirms the action of man on the destruction of the ozone layer. Roshan *et al.*, 2013, showed the effect of Global Warming on the Intensity and Frequency Curves of Precipitation in Iran. One year later, Orosa *et al.*, 2014, demonstrated the action of climate change on human health. Nematchoua *et al.*, 2014, showed the Impact of Climate Change on Outdoor Thermal Comfort in the Tropical Wet Zone. Several studies have also demonstrated the action of man on environment and the multiple consequences of climate change (Moisselin and Dubuisson, 2006; Roy, 1983; Jones and Moberg, 2003; Howden *et al.* 2007; Moisselin and Canellas, 2005). Africa, and other poor countries of the world that pollute less, suffer most from the consequences of global warming (Hulme *et al.*, 2001, Webster *et al.*, 2005; Zhang *et al.*, 2007). The choice of Madagascar as a study site has not been done randomly. Madagascar is considered as the third country that is most vulnerable to climate change worldwide. Ninety-five percent of its population is dependent on agriculture and is seriously threatened by the degree of heating. In the last (Lettre de politique,2015) ears (between 1980 and 1995), the average annual number of cyclones, with an intensity of three or more (winds above 150 km / hour) has increased (Rabefitia *et al.*, 2008; Zoaharimalala *et al.*, 2008). In Madagascar, the biomass represents about 90% of the primary energy resources used. The Wood Energy sector represents 93% of the energy transactions in Madagascar (NY Nandrasana *et al.*, 2014; AIDES, 2012; MINEH, 2015). Two-thirds of the population lives in rural areas. Madagascar has the largest number of lemurs in the world and two-thirds of the endangered chameleon. With an estimated annual growth rate of 2.8% population, the energy demand is increasing every year (Amédée, 2013). In this study, we have used the standard methods established by(IPPC,2007), to quantify the variation in the external environment, the state of the current location and the demand for energy over three periods (past, present and future).

2. Materials and methods

2.1 Study area

Located between 20°00 S and 47°00 E, Madagascar is almost entirely within the tropics. It is an island in the Indian Ocean with an area of 592.000 km². It is the fourth largest island in the world. It is separated from Africa by the Mozambique Channel, about 400 km away. A mountainous spine between 1200 m and 1500 m runs through the island from north to south along its length. This geographic landform, the maritime influence and the wind condition are the cause for the very varied climatic conditions encountered on this island. There are basically two seasons in Madagascar: the dry season from May to October and the rainy season from November to April. Two short seasons, with a duration of approximately one month each, separate these two seasons. From May to October the climate is conditioned by an anticyclone to the Indian Ocean level that directs a wind regime of South-East trade winds on Madagascar. During this season, the eastern part of the island, "in the wind," enjoys a humid climate, while the western part undergoes drought, a climate "downwind". In this part of the article we speak of the dry season or cool season (or winter) depending on the altitude of the place. During the summer or the warm season, the anticyclone of the Indian Ocean weakens and the trade wind regime become less regular, but the eastern part of Madagascar always remains under this influence. During this season, stormy instabilities develop almost daily, in all regions. The Intertropical Convergence Zone (ITCZ) extends its influence intermittently on Madagascar. Rainfall varies from 350 mm on the southwest coast to nearly 4000 mm in Baie.

2.2 Climatic data

In accordance with Rabefitia *et al.*, 2008 and Tadross *et al.*, 2008, outdoor daily data of temperature (minimum and maximum), precipitation and sunshine for the last 44 years (between 1961 and 2005) was taken in many meteorological stations. The various data were measured from 3 m to 10 m in height from the ground and with a frequency of 10–15 minutes. Figure1 shows the site of study and climate characteristics.

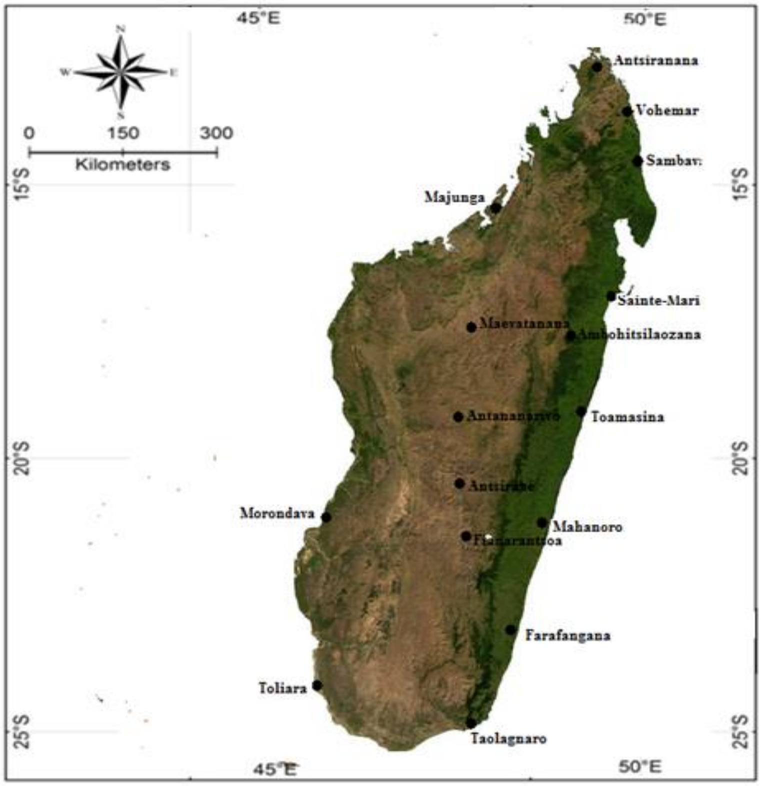

Figure1a. The cities studied

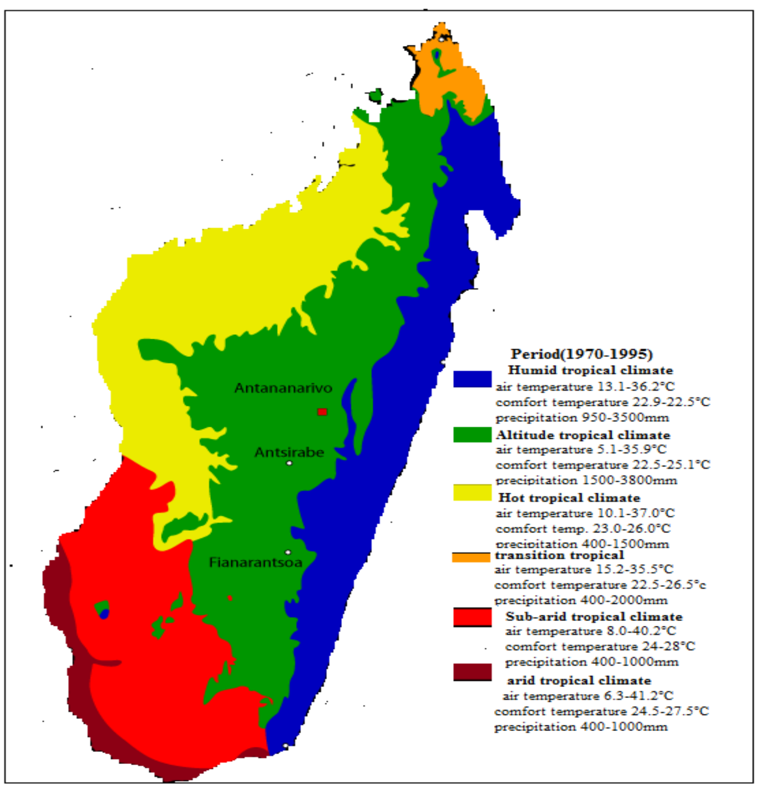

Figure1b. The characteristics of climate in different regions between 1970 and 1995

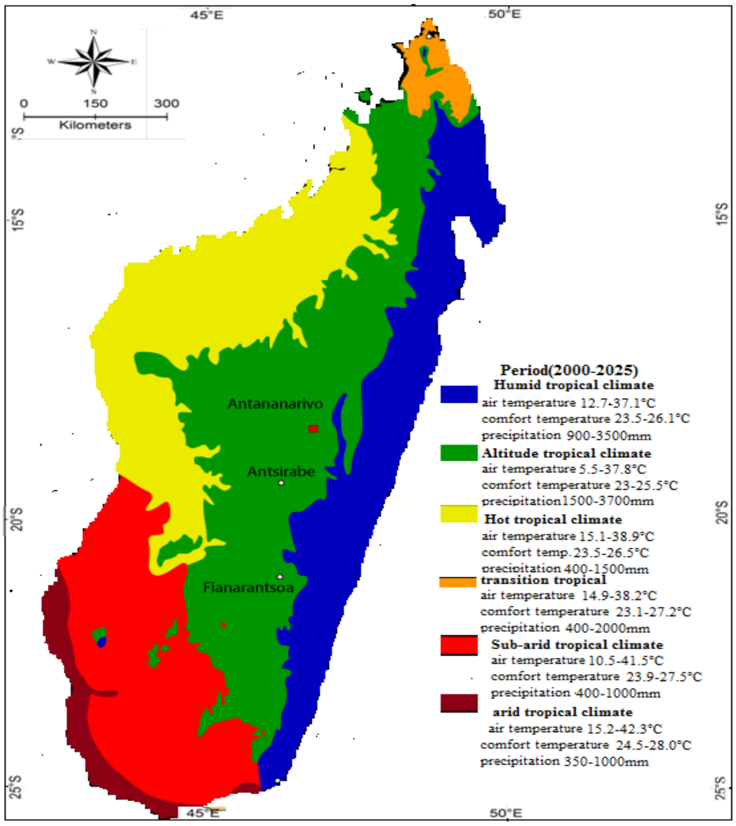

Figure1c. The characteristics of climate in different regions between 2000 and 2025

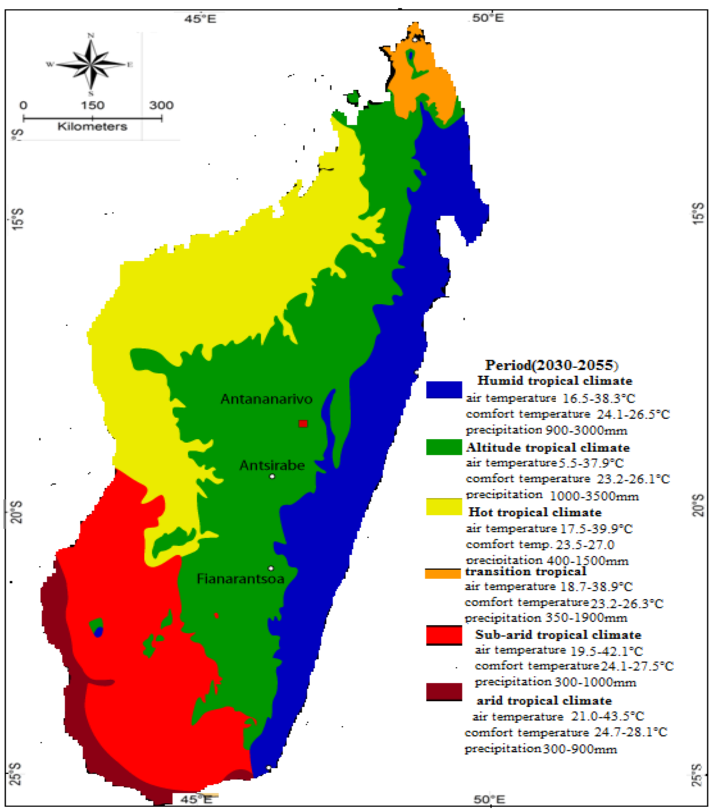

Figure1d. The characteristics of climate in different regions between 2030 and 2055

In Madagascar, the annual average temperature is between 14°C and 27.5°C. On the coast, it depends on the latitude and ranges from 27°C in the North and 23°C in the South. The west coast is warmer than the east coast (1°C to 3°C). On the plateaus, the average annual temperature ranges between 14°C and 22°C. The average temperature reaches its minimum in July across the country; the maximum occurs in January and February for most regions, except for a few places in the Highlands and the Northwestern region, where it is observed in November. In year 2000, the level of warming in the southern part of Madagascar was more significant than in the North. The dry sequences lie on the Central Highlands and the East Coast. On the Highlands, this is due to the decline of the rainy season. The changes in precipitation in Madagascar vary from one region to another. Rainfall becomes a lot more intense on the western part. Over the past 100 years, the level of rainfall in Madagascar has shown great variability. In the southern part, rainfall increases with temperature. In the northern part, precipitation increases with decreasing temperature. The quantity of annual precipitation decreases 5% per year, except from December to February, where we noticed an increase between 3% and 8%. In East and West, a maximum of 3700 mm per year was saved and from north to south a minimum of 350 mm per year. The seasonal increase is along the same direction — from the West to the South, the dry season becomes longer and a lot more pronounced (Tadross *et al.*, 2005).

2.3 Climate change models

Many models and scenarios can be used to simulate the variation of air temperature and precipitation. In the present research, 13 GCMs (BCCRBCM2, INMCM-30, NCARPCM1), combined with two scenarios have been used — A2 from Intergovernmental Panel on Climate Change (IPCC) (society will continue to use fossil fuels at a moderate rate, there will be less economic integration and populations will continue to increase) and A1B (a future world in which economic growth will be very fast and new and more efficient technologies will be quickly introduced). Finally, only the INCM3 model and scenario A2 were used to carry out the forecasting (Tadross *et al.*, 2005). Actually, the most significant input of these models is the rate of emission of greenhouse gases in the future eras. However, a precise final determination is not possible. Accordingly, different emission scenarios consisting of the quality of a variety of gases in the future have been offered. On the other hand, to define the effect of global warming by means of the rise in global temperature, it was necessary to employ a LARS-WG model. LARS-WG is one of the most well-known meteorological stochastic data-generating models used for the generation of quantities of rainfall, solar radiation and daily maximum and minimum temperatures in both the present and future climates of a meteorological station (Racsko *et al.*, 1991; Semenov, 2012). The first version of the above-mentioned model was invented as a tool for statistical exponential micro-scaling in Budapest in 1990 (Racsko *et al.*, 1991). In a LARS-WG model, some complex statistical distributions are used for making models of meteorological variables. Fourier's series estimates the temperature. Daily maximum and minimum temperatures are simulated as stochastic processes, with daily standard deviations and mean, depending on the dry or wet conditions of the relevant day (Orosa, 2014). In this assessment, Madagascar's temperature data in the time interval of 1901–2000 was chosen as the basic data and temperature changes in the years 1961–2005 were studied based on the proposed scenario, so that the proper model concurs with the experimental data of temperature in the proposed years. After testing the best model with the Pearson correlation coefficient, the changes of temperature in 16 regions in Madagascar were predicted in the worldwide heating bed for the period 2000–2100. On the basis of these changes, the degree day index values were calculated and compared with those in the past and present periods.

2.4 Energy consumption

To quantify the real outdoor warming energy in different seasons the methodology of IPPC, 2001 was used. This method is based on Eq. (1), which expresses the energy consumption required to maintain a comfortable outdoor environment. This equation depends on the ventilation mass flow rate, that is, the increase or decrease in outdoor air enthalpy required in terms of the desired indoor conditions, as shown in Eq. (2), and the period of time during which this difference exists.

$$Q = m_{ventilation} \int \Delta h . dt \qquad (1)$$

Where, $\Delta h = h_{outdoor} - h_{desired}$ (2)

$h_{outdoor}$ is the outdoor enthalpy and $h_{desired}$ is the desired indoor enthalpy.

The comfort temperature is defined according to the formula established in IPPC, 2001, depending on the outdoor climate. The formula below, which allows calculation of a comfortable temperature was tested and validated by many researchers in the sub-Saharan area, to establish a range of comfort in various places of their study. Hence, the ideal conditions required to cool and heat buildings can be defined according to this equation:

$$T_C = 0.534.T_O + 11.9 \qquad (3)$$

Where T_C is the indoor comfort temperature and T_O is the monthly mean outdoor temperature at the appropriate period of the year. This data (T_O) can be obtained from climatic conditions.

3. Results and Discussions

The original temperature increment had been assessed at the start of 1950 and 1970, which represented the years where the air temperature started to increase in the North and South of Madagascar. It was found that precipitation increased, while the temperature decreased in the North. However, in the South, precipitation increased with temperature. The minimum and maximum temperatures did not always remain constant. Sometimes, they showed a similar trend. Furthermore, the maximum temperature was changing faster than the minimum temperature. The minimum and maximum annual temperature in the northern region increased from 0.4 to 3.7°C and ranged between - 0.6 and + 2.4°C, respectively, between 1901 and 1970. On the other hand, after a decade, the minimum annual temperature was expected to increase from 2.6 to 3.3°C and the maximum annual temperature from 2.7 to 4.0°C in the southern region, as compared to that during 1901–2000. The seasons were disrupted due to the belated arrival of rains. These rains were very intense and often violent; with accentuated drought in the south; we noticed that the air temperature had risen generally. Figure 2 shows the Mean Partial Vapour Pressure difference in some regions of Madagascar with several types of climate in two periods: the past years (1975 and 2000) and the future (2025). A high intensity of pressure difference can explain the real effect of the action of external environment on the comfort of the environment. This directly affects the health of man, with a consequent decline in productivity. Taking into consideration the entire climate of Madagascar, the Mean Partial Vapour Pressure difference was higher in the year 1975 than in the years 2000 and 2025. The change in vapour partial pressure is more remarkable in the semi-arid tropical climate, with values that range from - 200 to 250 Pa, throughout the year. In addition, the Mean Partial Vapour Pressure difference is very high at elevated altitudes, with a peak of 554.2 pa, obtained in June. In the humid tropical regions (see Figure 2d), the air pressure starts to fall from March to November.

The Mean Partial Vapour Pressure difference is greater in the months of June, July and August, in all climate zones, except the humid zone. This may be because this region of Madagascar is regularly affected by cyclones and storms. A standard deviation (SD) of 112 is noticed in the semi-arid tropical climate. In transition, tropical climate the SD has been 67 and 88 in years 1975 and 2025.

Figure 3 shows the outdoor air enthalpy in Madagascar in different climates. In the arid climate, in year 1975, the enthalpy varied from 44 to 65 KJ/Kg, with SD = 7.4. On the other hand, in the years 2000 and 2025we saw different mean values of enthalpy — between 42 and 70 KJ/Kg, with SD=7.7 (see Figure 3a). Annually, the changing precipitation was not significant. However, there was a reduction in the amount of precipitation during the dry season, especially on the East Coast. The dry spells were getting longer and were accompanied by a delay in the start of the rainy season. Heating during the day would probably increase by around 10% in 2025; meanwhile the cooling degree during the day might decrease slightly. In a transitional tropical climate, the enthalpy varied from 55 KJ/Kg to 71 KJ/Kg with SD = 4.5 (in the year 1975); from 58 KJ/Kg to 73 KJ/Kg, with SD = 4.8 (in the year 2000) and might be from 57 KJ/Kg to 75KJ/Kg, with SD = 5.2, (in the year 2025). On the other hand, in an equatorial climate, the enthalpy was from 33.5 KJ/Kg to 53.5 KJ/Kg (in year 1975), from 35.2 KJ/Kg to 56.1KJ/Kg (in year 2000) and might be between 36.9 KJ/Kg and 58.4 KJ/Kg (in the year 2025). Finally, in a humid tropical climate, the enthalpy values would be the highest in 2025, with a peak obtained in September. The minimum was in March for all the studied periods. The enthalpy seemed to be moderate in the dry season (May–October). This could be due to the wet and cold wind that crossed several regions of the country during this period. In all regions of the country, the fluctuations were the weakest in the rainy season.

Figure 4 shows the enthalpy differences between outdoor conditions and ideal outdoor ambience in some regions of Madagascar. In the arid climate, the enthalpy differences decrease from January to May. Between June and September, the energy demand is very weak, but by October this energy demand increases very fast, to reach 4.8 KJ/Kg in December. Globally, in 1975, the mean monthly enthalpy differences were 0.43 KJ/Kg. After 25 years (in year 2000), the mean monthly enthalpy difference was already around 1 KJ/Kg; in 2025, if the pressure on environment stays the same, the mean monthly enthalpy difference will be 1.671 KJ/Kg. In a transitional climate, the enthalpy difference should be the highest in 2025. It will be same between June and September, with no energy demand, however in October, the enthalpy difference will increase till December. In addition, in a humid climate (see Figure 5), during April the enthalpy difference will increase up to December, after which it will seem to decrease.

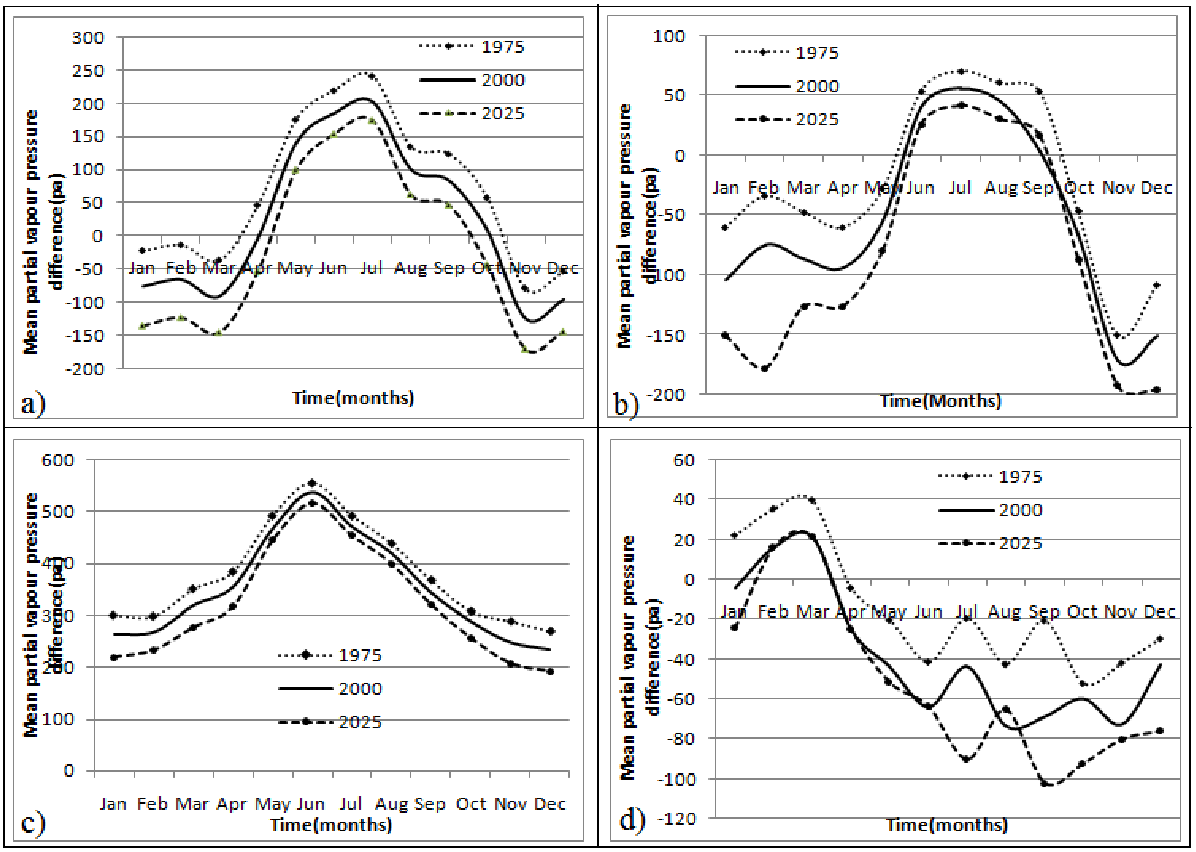

Figure 2. Mean partial vapour pressure difference in regions with semi arid tropical (a), transition tropical (b), equatorial (c) and humid tropical (d) climate

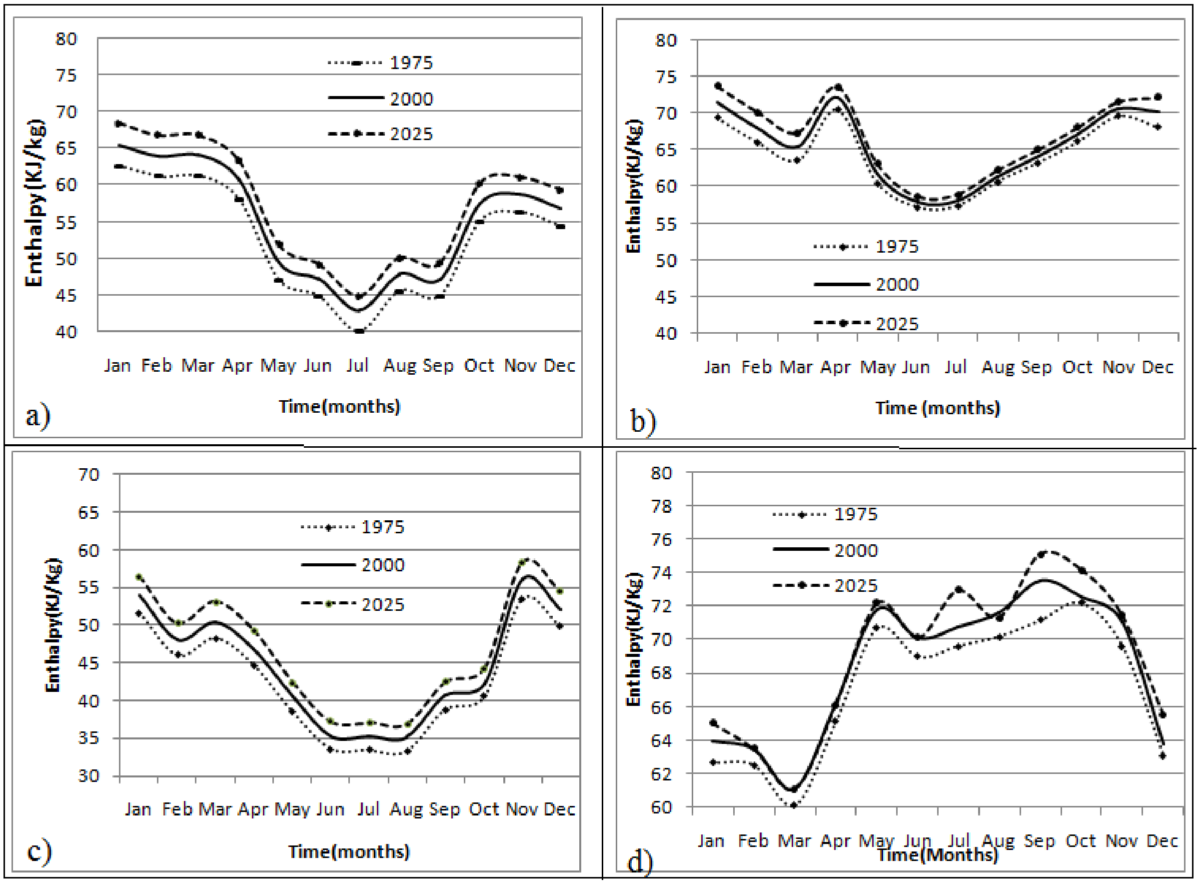

Figure 3. Outdoor air enthalpy in Madagascar in regions with semi arid tropical (a), transition tropical (b), equatorial (c) and humid tropical (d) climate

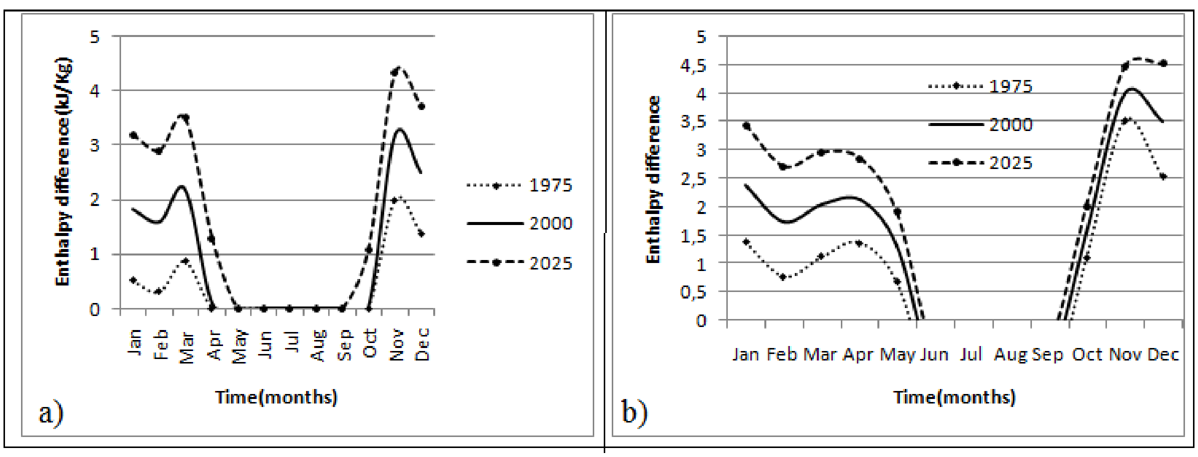

Figure 4. Enthalpy differences between outdoor conditions and ideal outdoor ambience in Madagascar in regions with semi arid tropical (a) and transition tropical (b) climate

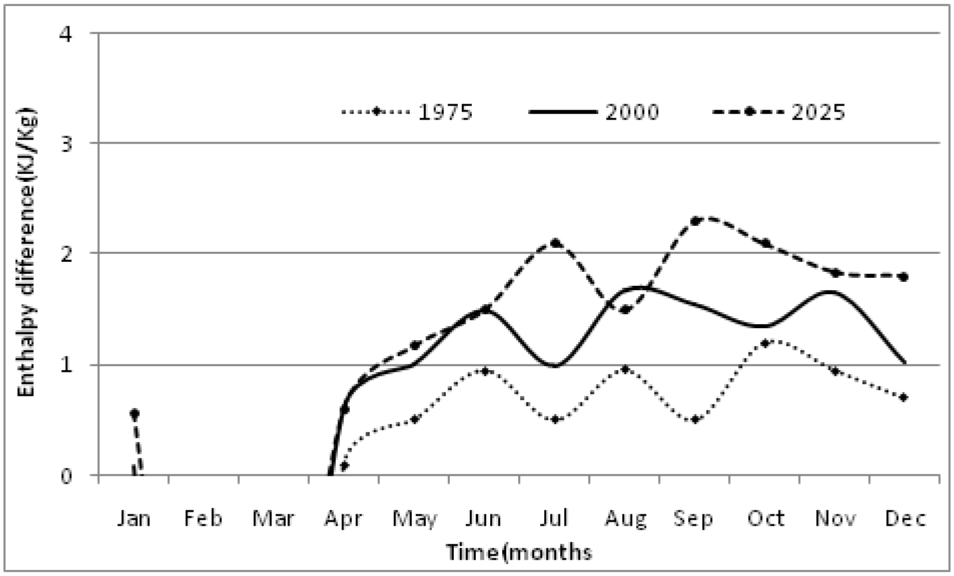

Figure 5. Enthalpy differences between outdoor conditions and ideal outdoor ambience in a Madagascar region with a tropical humid climate

Figure 6 shows the humidex index increment in several types of climate in Madagascar. It was found that in transitional tropical climate regions (Figure 6a) and humid tropical climate regions (Figure 6b), the environment was uncomfortable, because the humidex value was between 30 and 40. In a tropical transitional climate, the environment was acceptable between January and May, and then between September and December. During these months, the humidex index varied from 14 to 20. In June, July and August, the environment was uncomfortable as it was "too cool". In all types of climate, the humidex value would be the highest in the year 2025. It could be a consequence of global warming. In fact, the humidex value changed the functions of air temperature and relative humidity. For air temperature greater than 27°C and relative humidity above 60%, the middle uncomfortable, because of the high degree of heat. At the same humidity values, if the air temperature ranged from 10°C to 18°C, the medium would still be uncomfortable, but this would be because of the very high degree of cold. The outdoor environment would be really uncomfortable in the future, according to National Weather of Madagascar (Tadross,2008). In 2099, the air temperature would have increased from 0.5°C to 3°C, with an average rise of 0.5°C every 20 years. As for rainfall, annual rainfall would decrease to 5% at the end of the century in the whole island. It has nevertheless provided an increase of 5% to 10% of precipitation between December and February. Overall, the environment is acceptable or comfortable, when the air temperature ranges between 22°C and 26°C, with humidity between 35% and 65%. This comfort range established for different types of climate in Madagascar is very close to that established by some standard norms (ISO7730, 2006; ISO 10551, 2002; ASHRAE55, 2004), (air temperature from 23°C to 26°C and relative humidity between 30% and 60%).

In all the regions, during the rainy season, the humidex concentration increases, however, in winter (in Central Madagascar), the humidex concentration is very low due to a very low degree of humidity and very high air speeds, sometimes reaching 6.5 to 8.0 m/s (Kameni *et al.*, 2015).

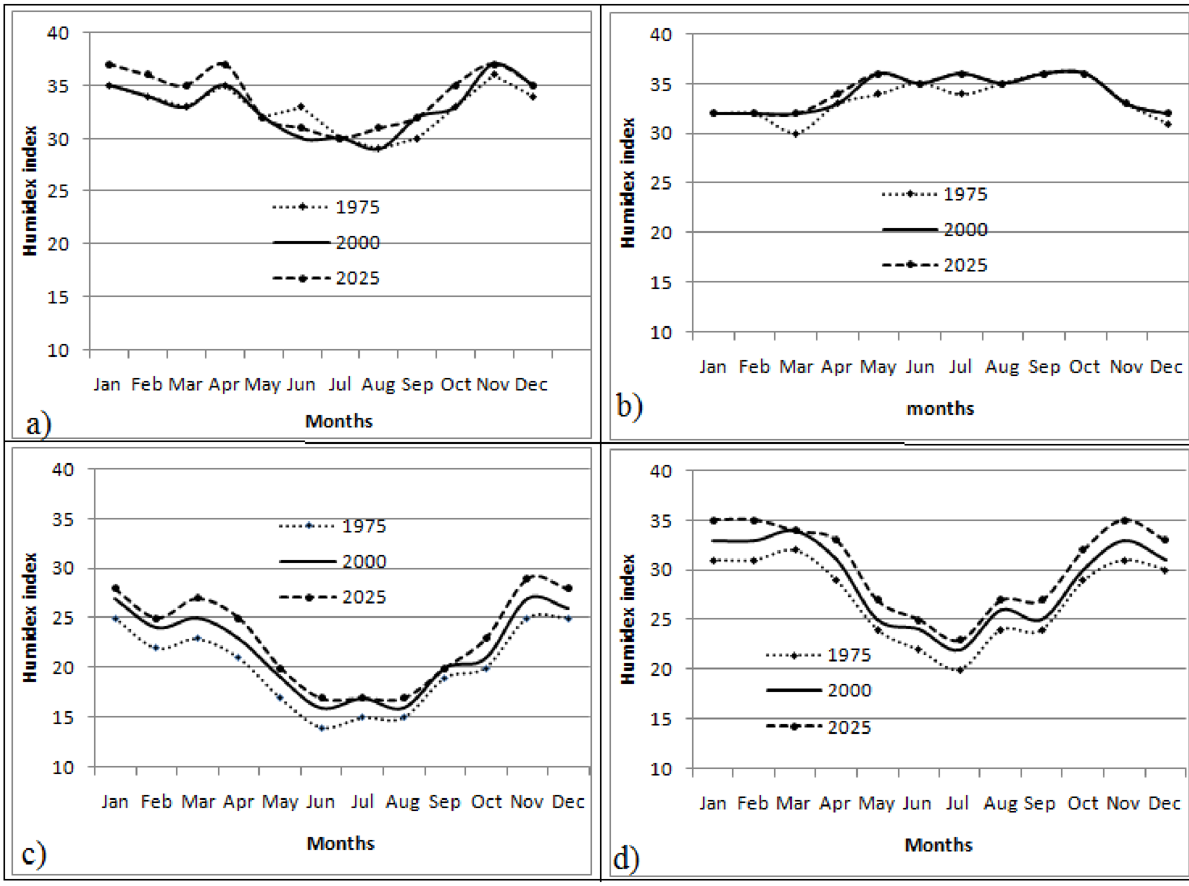

Figure 6. Humidex index increment in Madagascar for transitional tropical climate regions (a), humid tropical climate regions (b), altitude climate regions (c) and semi-arid tropical climate regions (d)

4. Conclusion

In this research, we have studied the variation of outdoor climate in some regions of Madagascar and also assessed the global warming impacts on energy demands in 16 regions in Madagascar. Several GCMs were combined with several scenarios to screen the Climate Change outside and to assess the state of comfort of the environment. Finally, we used the General Circulation Model INCM3 combined with scenario A2 to carry out the forecasting. The cooling energy demand will increase to 10% over the next 25 years in 90% of the studied regions in Madagascar. The partial vapour pressure values are not stable, sometimes they reach 250 pa in a semi-arid tropical climate. In the year 2000, the different average value of enthalpy was 42 KJ/Kg, which should increase till reach 70 KJ/Kg in 2025. A strong partial vapour pressure power in the coastal zones was noticed in the dry season, with an implication that the inhabitants would develop dry lips and cracked feet. During the rainy season, a higher heating degree would immediately lead to total discomfort and an increase in energy demand in the buildings. Further studies covering all countries in the Indian Ocean would allow us to have a database about the variations in climate, in this part of the globe.

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