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# Relationship between Atmospheric $CO_2$ Concentration and Vegetation in a Hospital Area: The Policlinico Umberto I in Rome

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## Abstract

The capability of the plants growing in the Policlinico Umberto I, one of the most important hospitals in Rome, to lower carbon dioxide ($CO_2$) and air temperature was analyzed. The $CO_2$ concentration inside and outside the hospital and traffic density in the streets surrounding the area was monitored monthly. Measurements of structural plant traits were carried out. The highest $CO_2$ concentration was monitored in winter-spring (425 ± 8 ppm, mean value) when traffic density peaks, decreasing by 17% in summer. During the day-time, the highest $CO_2$ concentration (433 ± 61 ppm, mean value) was measured in the first hours of the morning (9:00) decreasing by 12% from 11.00 to 13.00 in relationship with traffic density decreasing ($p < 0.05$). Among the greening present in the hospital area, the "group of trees" plays an important role in lowering $CO_2$ concentration compared to meadows. Moreover, outside the Policlinico air temperature was, on average, 17% higher compared to the inside. The results show the effectiveness of plants in improving air quality and suggest that greening traits may be used to realise an inventory available for tree planting programs to ameliorate the quality of life.

## Keywords

$CO_2$ Concentration, Hospital, Air Temperature, Green Cover

## 1. Introduction

Increasing greenhouse gas emissions in the atmosphere is one of the most important problems at a global level [1]. Climate change and urbanization represent two of the most critical points that are inextricably linked [2]. Over the 20th century, the atmospheric concentration of greenhouse gases is increased

due to human activities contributing to the global temperature increase [3]. Cities are responsible for 75% - 80% of global greenhouse gas emission [4]. It has been hypothesized that $CO_2$ emissions from road traffic worldwide will increase by 92% between 1990 and 2020 [5] affecting the environment, health and economy [6]. The problem is emphasized in those urban areas where vehicular traffic is the main source of greenhouse gases [7] and where the current urban dynamics is based on continuing trends of sprawl and as consequence with a high dependence on private motorized transportation can significantly contribute to the increase of gas emission rates [8]. Urban population is exposed to a greater risk of adverse health effects, which may be attributed to increased exposure to particulate matter and gaseous pollutants emitted by vehicular traffic. These pollutants pose a direct and serious hazard to living organisms in general and to humans in particular [9]. High levels of vehicle emissions in cities are related to the rising trend in allergic respiratory diseases [10] with a direct relationship between motor vehicle exhausts and acute or chronic respiratory symptoms in children living near high traffic level areas. Urban greening can reduce the population's exposure to air pollution through the interception of airborne particles on the leaf surface or inside the leaf tissues via roots [11] or the uptake of carbon dioxide ($CO_2$) via stomata [12]. A growing body of research in outdoor environmental contexts, such as public urban spaces, residential settings, schools and hospitals shows that a view of the greening enhances health and reduces stress [13]. Moreover, research on urban parks demonstrates a positive relationship between availability of green areas and children and adolescents' physical activity [14] as well as creative play [15]. Nevertheless, similar studies are not available for hospital healing gardens. Moreover, visitors and patients walking behavior varied in response to the hospital garden's design characteristics (extrovert walking versus introvert walking) [16]. Dismissed as peripheral to medical treatments for much of the 20th century, gardens are back in style, now featured in the design of most new hospitals, according to the American Society of Landscape Architects. Previous studies suggest that design factors such as poor shading, planting and seating options influence usability of gardens in hospitals [17] and urban setting [18]. Several studies have found reduction in stress levels and health-related complaints among patients and staff [19] who were provided with windows overlooking gardens. Moreover, there has been indirect evidence that access to hospital gardens increases patient and staff satisfaction with the overall hospital experience [17]. Thus, healthcare specialists, architects and landscape designers should consider that the hospital environment might affect the mood, stress level and well-being of patients and their families [20]. In such context, the main objective of the present research was to assess the carbon dioxide ($CO_2$) concentration variations inside and outside the Policlinico Umberto I, one of the most important hospitals in Rome, considering the role of the greening in improving air quality. The collected data may be used for an inventory available for green furniture projects to improve the quality of life in protected areas such as hospitals, schools and shelters.

## 2. Materials and Methods

### 2.1. Study Area

The study was carried in the period January-July 2015 in the area of the Policlinico Umberto I in Rome (41˚54'26.9"N, 12˚30'42.9"E, Italy). The Hospital covers an area of 150,000 $m^2$ and is bounded on the north face by Giovanni Maria Lancisi Street, on the east face by Regina Elena Avenue, on the south face by University Avenue and on the west face by the Policlinico Avenue, all characterized by an all-day high traffic level. The Policlinico Umberto I has 1500 beds and several medicine, diagnostics and surgery outpatients. It is a centre of cultural exchange at national and international level. Moreover, the hospital is characterized by a high traffic level both inside and outside and by a large extent of the greening, in particular, meadow and "group of trees".

Ten sites were selected along two transects crossing the hospital from outside to the inside, according to [21]. Among the considered sites, six sites were inside (Is) and four outside (Os) the hospital and corresponding to the public entries. In particular, among Is, two sites were characterized by meadow (Ms1 and Ms2), two by "group of trees" (Ts1 and Ts2) and two without vegetation (Es1 and Es2). Ms1 and Ms2 had the same extension, and Ts1 and Ts2 had by different tree species (20 ± 5 and 10 ± 3 evergreen and deciduous trees in Ts1 and Ts2, respectively).

Rome is under a Mediterranean type of climate. Most of the total annual rainfall (866 mm) is distributed in autumn-winter and drought is from June to August. The mean air temperature is 16.4˚C ± 6.5˚C, the mean minimum air temperature of the coldest months (January and February) 4.9˚C ± 0.1˚C and the mean maximum air temperature of the hottest month (August) 31.7˚C ± 1.4˚C. During the study period the mean minimum air temperature of the coldest months (January and February) was 4.5˚C ± 0.1˚C, the mean maximum air temperature of the hottest month (July) 33.9˚C ± 1.2˚C and total rainfall 502 mm (data provided by Lazio Regional Agency for Development and Agricultural Innovation, Rome, for the period 2006-2015).

### 2.2. Plant Traits

The extent of meadow (Ms) and "group of trees" (Ts) inside the Policlinico Umberto I was measured by the QGIS (Geographic Information System). QGIS determines the acquisition, recording, analysis, visualization and restitution of information by geographical data. The GIS software is useful for the census of urban green areas by analysis of the digital cartographies.

The structural traits of the "group of trees" included tree diameter at breast height (DBH, cm) measured by calipers and plant height (H, m) by clinometers. The number of trees for each species in the "group of trees" was counted.

### 2.3. Carbon Dioxide Concentration and Traffic Density

The atmospheric carbon dioxide ($CO_2$, ppm) concentration was carried out

monthly (three sampling days per month with comparable climatic conditions, almost 3 days after the last rainfall) during the study period. The $CO_2$ concentration was measured in each site, every two hours from 9.00 h to 17.00 h, by a $CO_2$ gas analyzer (ADC, Bioscientific LTD, UK) at 1.50 m from the soil, according to [22].

Traffic density (*i.e.* number of car per minute) was measured simultaneously with $CO_2$ measurements in each of the considered sites inside and outside the hospital. In particular, outside the Policlinico, traffic density was measured at Giovanni Maria Lancisi Street, Regina Elena Avenue, University Avenue and Policlinico Avenue.

### 2.4. Microclimate Measurements

Microclimate measurements were carried out simultaneously with $CO_2$ measurements, in each of the considered sites. Air temperature ($T_a$, ˚C) and humidity (Rh, %) were measured by a portable thermo-hygrometer (HD 8901, Delta Ohm, I).

### 2.5. Statistical Analysis

Differences of the means were tested by one-way analysis of variance (ANOVA) and Tukey test for multiple comparisons. A simple regression analysis was used to analyze the correlation between traffic level and atmospheric $CO_2$ concentration. All statistical tests were performed using a statistical software package (Statistica, Statsoft, USA).

## 3. Results and Discussion

Urban greening can generate significant ecosystem services such as offsetting carbon emissions [23] [24], removing air pollutants [11] reducing noise [25], regulating microclimate [26] and favouring recreation and amenity [27]. Plants act as sink for $CO_2$ by fixing carbon during photosynthesis and storing the excess as biomass [28]. This plant function is particularly important in protected areas such as hospitals, schools and shelters [29]. Nevertheless, without detailed local data, urban vegetation managers cannot easily design and implement strategies to maximize a particular vegetation's desired ecological functions, and thus, protect and enhance its value [30].

Inside the Policlinico Umberto I, meadows cover 11,409 $m^2$ and the "group of trees" 18,773 $m^2$. In particular, at Ts1 most of the trees are evergreens while at Ts2 deciduous species. Among the evergreen trees, 45% are *Quercus ilex*, 20% *Phoenix canariensis*, 15% *Pinus pinea*, 15% *Magnolia grandiflora* and 5% *Cupressus sempervirens*. Among the deciduous trees, 60% are *Tilia platyphyllos* and 40% *Platanus hybrida* (mean value of Ts1 and Ts2, respectively). The considered trees have a height of 13.6 ± 6.8 m and a diameter of 0.50 ± 0.24 m, respectively (mean value of the tree species) (**Table 1**).

During the year, the highest $CO_2$ concentration is monitored in winter-spring (425 ± 8 ppm, mean value) (**Figure 1**) when the traffic density peaks (10 ± 8

**Table 1.** Structural traits of the considered tree species; H = plant height, DBH = diameter at breast height.

| Species | H (m) | DBH (m) |
|---|---|---|
| *Quercus ilex* | 8.43 ± 4.85 | 0.31 ± 0.27 |
| *Phoenix canariensis* | 11.67 ± 5.76 | 0.41 ± 0.30 |
| *Magnolia grandiflora* | 6.53 ± 4.26 | 0.17 ± 0.17 |
| *Cupressus sempervirens* | 24.36 ± 2.90 | 0.78 ± 0.12 |
| *Pinus pinea* | 19.45 ± 2.55 | 0.65 ± 0.17 |
| *Platanus hybrida* | 13.46 ± 2.02 | 0.66 ± 0.06 |
| *Tilia platyphyllos* | 11.21 ± 1.30 | 0.48 ± 0.03 |

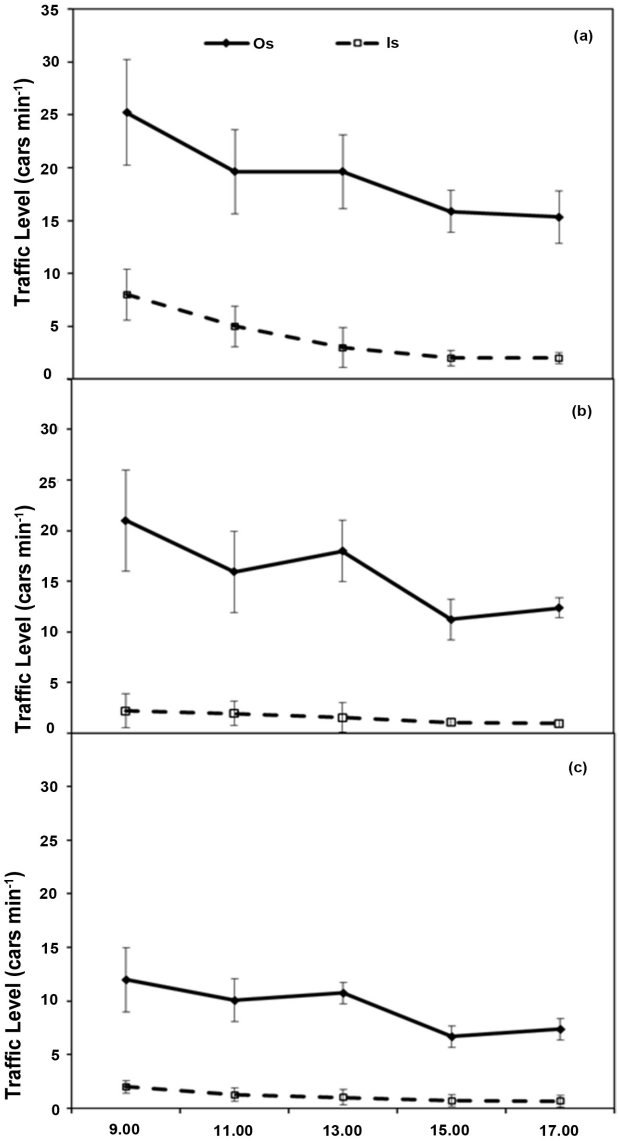


**Figure 1.** Daily traffic density (number of cars per minute) monitored in the considered sites inside (Is, dotted line) and outside the Policlinico Umberto I (Os, black line) from 09:00 h to 17.00 h, in winter (a), spring (b) and summer (c). Mean value (±S.D., n = 3 per each considered site and hour) is shown. The differences between Is and Os are always significant ($p < 0.05$).

car·min$^{-1}$), decreasing by 17% in summer when the traffic density decreases by 50%, as confirmed by the significant positive correlation ($r$ = 0.527, p < 0.05) between $CO_2$ concentration and traffic density. The day-time $CO_2$ trend (Figure 2) shows the highest concentration (433 ± 61 ppm, mean value) in the considered sites (*i.e.* Is and Os) in the first hours of the morning (9:00) decreasing by 12% from 11.00 to 13.00 in relationship with traffic density decrease (Figure 3). The 2.5% atmospheric $CO_2$ concentration increasing at 17.00 can be justified by the plant respiration/photosynthesis ratio increasing from the afternoon until the first hours of the morning. The results highlight the role of the greening in decreasing atmospheric $CO_2$ inside the Policlinico Umberto I. In particular, the "group of trees" decreases atmospheric $CO_2$ concentration by 20% than the outside, followed by meadows (14%) (Figure 4). Moreover, the greening has an

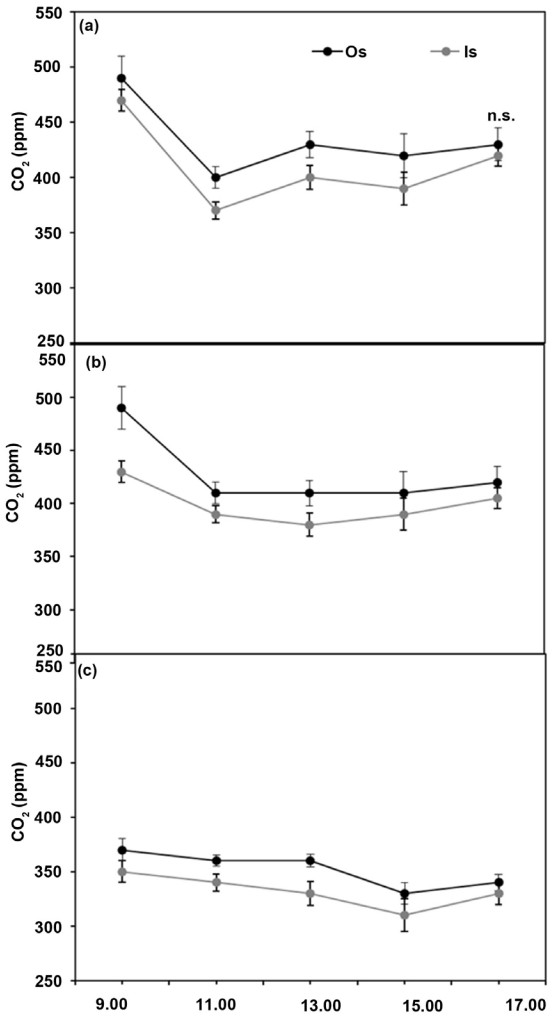


Figure 2. Daily $CO_2$ concentration (ppm) trend monitored in the considered sites inside (Is, grey line) and outside the Policlinico Umberto I (Os, blank line) from 09:00 h to 17.00 h, in winter (a), spring (B) and summer (c). Mean value (±S.D., n = 3 per each considered site and hour) is shown. The differences between Is and Os are always significant excepted when indicated (n.s., p > 0.05).

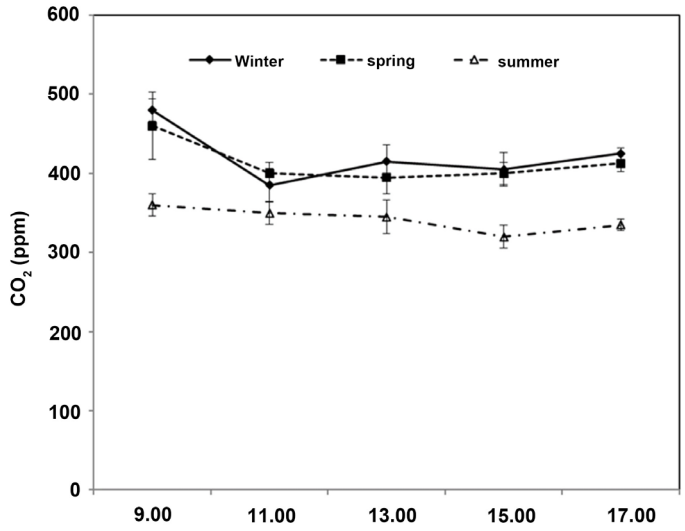


**Figure 3.** Daily $CO_2$ concentration (ppm) trend in winter, spring and summer. Mean values (±S.D.) of the considered sites inside (Is) and outside (Os) are shown (n = 3 per each considered site and hour). Different lower-case letters indicate significant differences between seasons within the same hour at $p \leq 0.05$.

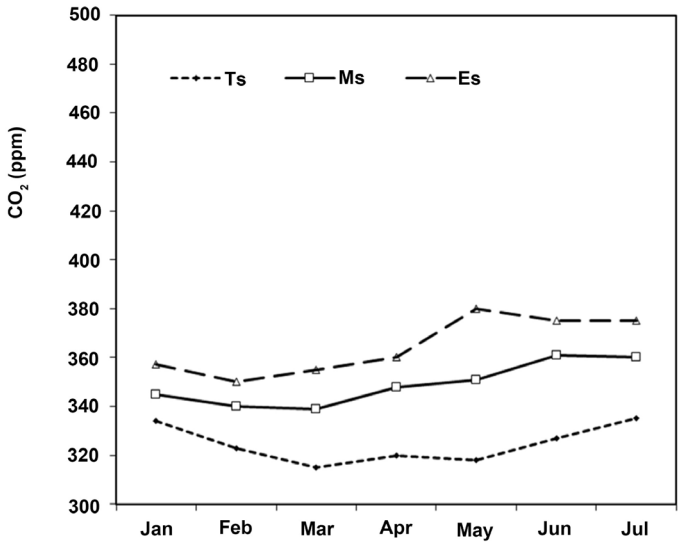


**Figure 4.** Monthly $CO_2$ concentration (ppm) trend in the sites characterized by the presence of meadow (Ms), "group of trees" (Ts) and in absence of vegetation (Es). Mean values (±S.D.) of two Ms, Ts and Es sites per each sampling occasion are shown (n = 3 per each considered site and month). * indicates significant differences between the considered sites within the same month at $p \leq 0.05$.

important role in improving people well-being particularly for hospitalized people. Studies show that post-surgical hospital patients with window views of green landscapes have a significantly shorter recovery period and reduced need for pain medication compared to patients with views of urban settings [31] and children's health and emotional status benefit from day-care centres with vege-

tation [29] [32]. Moreover, planted trees can indirectly reduce $CO_2$ emissions associated with electric power production and consumption of natural gas by reducing the demand for heating and air conditioning in the buildings they shelter [33]. Trees represent also excellent regulators of air temperature by shade and transpiration [24]. Accordingly, our results show that outside the Policlinico air temperature was, on average, 17% higher compared to the inside (**Figure 5**), especially in March (30%) and in July (25%). An opposite trend was observed for air humidity, as attested by the correlation between the two variables (slope = −0.81; $r = 0.45$; $p < 0.0001$), resulting 18% higher inside than outside the hospital (**Figure 5**). Moreover, the evergreen species, such as *Q. ilex, P. canariensis, M.*

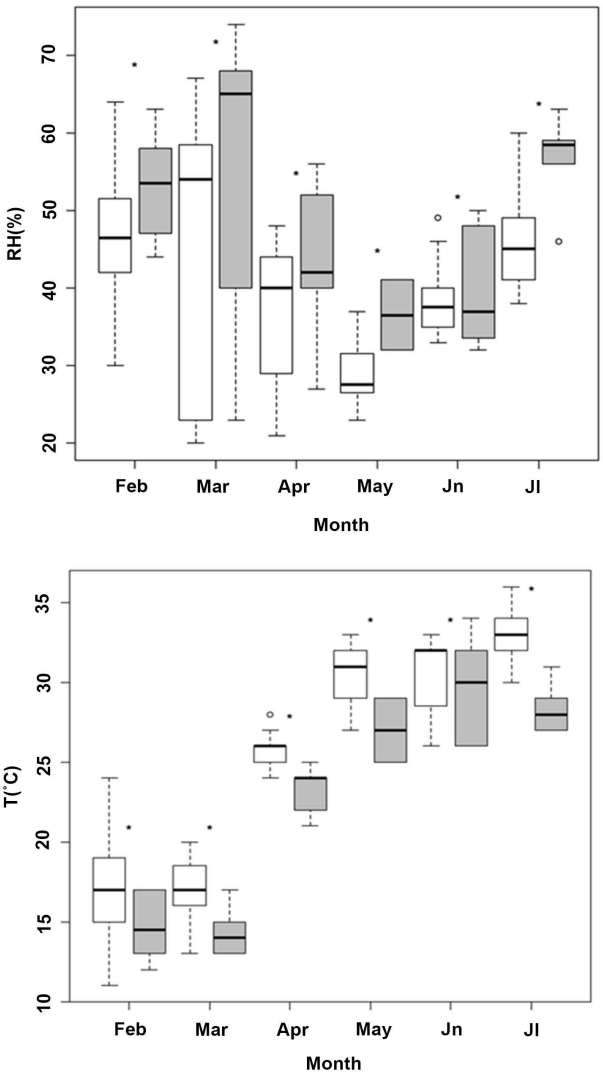


**Figure 5.** Monthly trends of air temperature ($T_a$, ˚C) and humidity (Rh, %) monitored in the sites inside (Is, gray boxes) and outside (Os, white boxes) the Policlinico Umberto I. Mean values (±S.D.) of Is sites and Os sites are shown (n = 3 per each considered site and hour). The first and third quartiles are also shown. * indicates significant differences between Is and Os within the same month at $p \leq 0.05$.

*grandifolia, C. sempervirens* and *P. pinea*, by their continuous photosynthetic activity throughout the year, contribute to reduce $CO_2$ also in winter when the traffic is the highest, as attested by the 67% higher traffic density compared to that monitored in spring and in summer. This role is very important in hospitals where the audience turnout is higher in winter. Several studies have shown the distribution of cumulative monthly deaths with a marked winter predominance [34] as well as an increase in respiratory and cardiovascular morbidity and mortality [35].

## 4. Conclusion

On the whole, the results highlight that both evergreens and deciduous species contribute to decreasing air temperature in summer ($T_a$ is 13% lower in Ts than in Es). Thus, plants in the city not only have an ornamental role but they may have also a role in regulating environmental functions. The type of greening (*i.e.* meadows and "group of trees") and plant habitus (*i.e.* evergreens and deciduous species) are likely to affect this cooling potential and the carbon sink capability. Accordingly, our results show 8% lower $CO_2$ concentration in Ts compared to Ms attesting the greater carbon storage capability of trees. Green coverage can be incorporated in a geographic information system facilitating vegetation management through spatial analysis and identifying landscape features. Moreover, the choice of plant species might be set out favouring those species taking into account their own air amelioration capability. Plant traits of each species may be used to realise an inventory available for tree planting programs to ameliorate the quality of life.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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