

# Investigation of Environmental Quality of Roads in Heraklion, Crete

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**Abstract:** This paper analyzes the parameters that determine and affect the environmental quality of urban roads. These parameters are grouped in five categories: bio-climatic, urban planning, traffic parameters, artificial elements and other parameters. After theoretically analysing all the parameters of the above categories, they are tested in practice for 16 representative roads of the urban complex of Heraklion. Following this, we compare the results of the above-mentioned analysis that can be quantified and draw certain conclusions for the current environmental quality of the roads examined and, by extension, for all the roads of the urban complex of Heraklion. Based on these conclusions, we propose certain interventions for upgrading the environmental quality of the city's roads that are of relevance to the state, as well as to the private sector.

**Keywords:** environmental quality, urban roads, bio-climatic, urban planning, traffic parameters, Heraklion

## 1 Introduction

The public, open areas of a city, i.e. the roads, squares, gardens, churchyards, archaeological sites, are the ones that make up the picture of a city, with the figures, the dimensions, the analogies and the perspectives that they create and the buildings that surround them. It is exactly the picture experienced and perceived by the resident/citizen and the picture gathered by the visitor, who returns to his or her hometown [1].

The majority of citizens are used to consider the public space as being a remainder of the private space, as a resulting space and not as a space designed. "People draw blocks in the form of regular shapes and they name the remainder roads and squares", writes C. Siite.

In this way, the road continues to be an area of movement, and not an area of transport, in which the notion of the interim space disappears, transferring the importance towards the starting and the ending points of the path [2]. The par excellence social area of the city, the road, is substantial only when it offers the minimum environmental conditions that will allow residents to move safely, as well as enjoyably [3].

Today, the urban road is the infrastructure for vehicles (moving and stationing), people (as an area for playing, meeting, demonstrating, speaking, walking, parading, socialising, etc.), as well as for cyclists and public transport. Depending

on the values of the individual society, its economic and cultural level, as well as on the technology available, the same area can be distributed differently among the various uses and users.

In addition to the road, per se, its equipment is also an important means which, when used properly, contributes positively to the formation of the road environment, while being also directly related to the mood and the picture finally gathered by the user (pedestrian, driver, passenger, permanent resident, visitor, etc.).

Another important parameter is also the materials used for roads and pavements, as well as for roadside buildings, as they affect the micro-climate, the amenities of open areas, and the energy efficiency of the surrounding buildings.

## 2 Factors - indices of environmental quality of urban roads

As mentioned above, the factors-indices of the environmental quality of the urban roads examined are grouped into five categories, as illustrated in the table below:

<b>Bio-climatic Parameters</b>	insolation - Sun protection Ventilation - Wind protection Air pollution Noise Visual disturbance
<b>Urban Planning Parameters</b>	Building permit limits - building heights Building density and system Road orientation - profiles Building forms Border spaces Pavements - with a direct impact: Pedestrian streets One-/two-way roads Cycle lanes - with an indirect impact: Traffic load Traffic makeup Average movement speed Parking locations and patterns Longitudinal slopes
<b>Traffic Parameters</b>	
<b>Artificial Elements</b>	Road pavement materials, road surface condition Roadside construction materials Road equipment Artificial lighting Green elements
<b>Other Parameters</b>	Population density Inward and outward movements Means of transport User safety Cleanliness and hygiene Preservation, rehabilitation and reuse of historical and cultural resources Land value

Table 1: Environmental quality indices

## 2.1 Detailed presentation of environmental quality indices

### 2.1.1 Insolation – Sun protection

The parameters affecting the insolation of a road are its orientation, the inclination and the mutual shading of the surfaces surrounding it. The orientation and inclination of a surface in relation to the horizontal level affect the intensity of incident solar radiation and the possibility of it being shaded by nearby surfaces. Regardless of the orientation and inclination of a surface, its shading depends on its geometrical relation to nearby surfaces, the geographical latitude of a location, the

season of the year and the specific moment examined. Given the latitude and the prevailing atmospheric conditions of a location, the main factors affecting the insolation of the city's roads are their orientation and cross-sections. In this sense, a road with a N-S direction presents a symmetrical access to the sun, while a road with a E-W direction is insolated assymmetrically, because it is open to the sunlight only on its southern part. In both cases, the view of the sun is a function of the h/w ratio, as analysed below.

### 2.1.2 Ventilation– Wind protection

The wind movement pattern within cities is a function of the urban web's geometry. In areas where the roads extend parallel to the wind direction, the air moves more freely. The linear urban structures, such as buildings, can create a channel phenomenon, i.e. the acceleration of wind and the formation of an undesirable environment (eddies and swirls). The phenomenon develops on roads longer than 100-125 m. A protection measure can be the planting of roads, so as to increase resistance to the wind and decrease its speed. Vegetation is very effective in preventing winds, given that the tree branches and leafage decelerate the wind without causing too much swirling. Studies show that slightly closed lines of plants offer the optimum and more homogeneous protection (50-65% opening surface). It is important for the zone of plants to provide the same level of protection throughout its height. It may therefore be necessary to combine different types of vegetation, e.g. to use trees for protection at a given height and bushes for protection close to the ground. Such series of plants can provide protection at a length equalling 4 or 5 times their height [4].

The wider the roads, the lesser the resistance developing to the movement of winds. When the wind direction forms an acute angle with the road, the movement is divided into two parts, one of which extends along the direction of the road [5].

### 2.1.3 Air pollution

Factors like the over-concentration of people and activities, the gradual decrease of open areas, particularly of implanted and leisure areas, the excessive role of the private car, the uncontrolled construction patterns and the obstruction of natural ventilation do indeed aggravate the city's air.

The above parameters, combined with the terrain, the speed and the direction of the area's prevailing winds, as well as the variation of temperatures depending on the height, lead to the formation of the smog, which the city's functions and production activities cause on a daily basis,

even though it is apparent only under specific meteorological conditions.

#### 2.1.4 Noise

In cities, the acoustic effect of an open area is of particular importance. The limits and elements of a landscape can cause resonance, thus affecting the acoustic convenience [4].

Roadside equipment (light posts, fences, walls, benches, phone booths, etc.) is a very efficient way to reduce noise. Also, vegetation along the building facades and on the ground can increase the dispersion of noise at the limit points, thus reducing the noise levels even more. The effectiveness of vegetation in urban areas is more significant compared to open areas, due to the multiple reflections. It is in this way that trees in urban areas increase the absorption and dispersion of noise [4].

#### 2.1.5 Visual disturbance

Visual convenience is referred to as a parameter of quality deriving from the design of the open area, in general, and the road, in particular. The latter is adapted to the utilisation of the natural light source during the day, i.e. the sunlight. The penetration of natural light into the urban complex has been characterised as an important quality parameter that must be ensured, particularly in densely populated cities.

#### 2.1.6 Building permit limits – building heights

The building permit limit is a combination of the plot coverage percentage and the number of storeys, since it expresses the relation of the total surface area of a building's storeys to the surface area of the plot.

In Greece, it is common to use higher building permit limits (bpl), compared to other European countries, on the grounds that the land value is high, as is also the sunshine in our country, while other factors are ignored, such as the need to enable unobstructed view and to ensure isolation, to allow for green and uncovered areas, etc.

Generally speaking, acceptable bpl values for areas of permanent residence are those ranging from 0.3 to 1.5. The more acceptable bpl values are those ranging from 0.6 to 1.0, given that the areas that develop within these limits present a relative economisation, in terms of land and infrastructures cost, and succeed in establishing the necessary social environment, while not being burdened by the problems of dense building patterns.

Areas with a bpl ranging from 1.0 to 1.5 are problematic in terms of insolation, lighting, direct view and isolation, if not for the entirety, at least for some parts of their building volumes [6].

The height of buildings is closely linked to the number of storeys, while the limit of the general

construction regulation is a maximum height of 1.5 w (w = road width + border space, where compulsory).

#### 2.1.7 Construction density and system

The construction density and system affect indirectly the environmental quality of roads, given that they affect the movement of air, the insolation, the visibility of the skydome, the incidence and absorption of solar radiation and the emission of thermal radiation. All of the above factors play a determining role in the temperatures developing in the air and on the surfaces, in the lighting and ventilation conditions, in the cooling of interior and exterior spaces, as well as in the concentration or the dispersion of air pollutants. More in particular, the multi- or single-storey buildings that are open on all sides can provide better conditions of insolation and ventilation, as well as offer more space for plants. However, the area of their exposed surfaces increases, causing a corresponding increase of their thermal loads, while the increase of distances between the land uses results into an increase of the energy cost of movements within and around the city.

The linear construction pattern and the multi-storey buildings have a small outer exposed area per ground surface area unit, which translates into lower thermal loads. However, their mutual shading is increased and the visibility of the skydome is deteriorated, as are also the ventilation conditions of the buildings and the retention of air pollutants [5].

#### 2.1.8 Road orientation and cross-section

The orientation and cross-section of the roads affect the insolation of the roads, and their ventilation.

For a wind blow perpendicular to the axis of a road surrounded by buildings that are open on all their sides, when the h/w ratio (height of the building's facade / road width) is lower than 0.4, the flow of air is almost similar to that of the countryside. When the distance decreases and the h/w ratio is lower than 0.7, air mixing is observed, while for even shorter distances, the wind blows grazingly over the terraces, causing eddies between the buildings.

For a wind blow perpendicular to the axis of a road surrounded by buildings that extend linearly, when the h/w ratio is lower than 0.3, the air flow is almost similar to that of the countryside, while, when the distance decreases and the h/w ratio is lower than 0.65, air mixing is observed [5].

#### 2.1.9 Building forms

The form of the existing buildings affects, in a determining and multi-faceted manner, the quality

of the environment in a city's web, since it determines the limits of roads and open spaces and affects their insolation and ventilation. Depending on the surface area, the materials, the construction methods and the micro-climatic conditions, it also affects the consumption of natural resources and energy, it determines the picture of the road and the public open space and, finally, accounts for the history and development of the locality [7].

### 2.1.10 Border spaces

Border spaces are zones of protection between the buildings and the road, with the aim to protect the building from the road, as well as the road from the building, by contributing to the safety of the road in relation to the roadside buildings, in cases of catastrophic events (earthquakes, fires, explosions, etc.), to the avoidance of risks caused by building site activities for road users, to the reduction of disturbance caused by the transportation of goods, the stowage of materials, etc. They also contribute to the aesthetics and the functionality of the common use spaces of buildings (plants, building infrastructures, "furniture – equipment", etc.) [8].

### 2.1.11 Pavements

For pedestrians moving on pavements or cross-walks, an axial distance of 1.00 m is considered acceptable along the movement direction, together with a transversal axial distance of 0.75 m for a single traffic direction and 0.60 m for two traffic directions. This has led to the establishment of a minimum pavement width of 1.50 m for urban road cross-sections [9].

The transversal axial distance increases to 1.00 m, when the person moving holds something in his/her hands (umbrella, stick, etc.) and to 1.50 m, when he/she accompanies a child.

As pertains to the construction materials, it is accepted that they must ensure an anti-slippery surface, as well as homogeneity, stability, durability and ease of cleaning and maintenance.

Other elements of the pavement, such as road grates, gutters, joints, etc. should not alter the homogeneity of the pavement floor. Particular attention must be paid to the drainage of rainwater. The catch basin grates must not extend more than 2 cm above the pavement surface, and must be placed outside the free movement zone.

It is necessary to provide adequate formations, for the pavements to be used by persons with disabilities.

### 2.1.12 Traffic load

On roads with dense traffic patterns, the average noise level is reduced by 3 dB (A), when the distance is doubled [10].

The increase of the traffic load results into a respective increase of pollutant emissions, as well as the cutoff, visual and physical, of the two opposite pavements.

### 2.1.13 Traffic composition

The participation, by 20 percent, of heavy vehicles, to the overall traffic increases the average noise level by 6 dB (A), compared to passenger vehicle-only traffic. If this participation index increases to 50 percent, the noise level increase observed will rise to 8 dB (A). Finally, if traffic is composed by heavy vehicles only (100 percent participation), the noise level increase, compared to passenger vehicle-only traffic, will be 10 dB (A) [10].

As pertains to the atmospheric pollution, the partial replacement of passenger vehicles by trucks would lead to an increase of the pollutants emitted. Taking into account the difference of the fuel used (diesel fuel in lieu of petrol), the rise in some of the pollutants emitted can be dramatic.

### 2.1.14 Average movement speed

The width of the traffic lane, as well as the existence of auxiliary lanes, do affect the average movement speed. Thus, for passenger car traffic, an increase from 80 to 100 km/h, results into an average increase of the noise level by 4 dB (A), while an increase of the speed from 80 to 120 km/h results into a 7 dB (A) increase. On the contrary, when the speed increases from 60 to 80 km/h, the average noise level remains unchanged [10].

However, the change of the average speed within the above margins, leads to better fuel utilisation and, consequently, to lower pollutant emissions.

### 2.1.15 Parking places and pattern

Roadside parking requires more manoeuvres in relation to angle-parking and, consequently, higher fuel consumption and pollutant emissions. Manoeuvring, in turn, requires more use of the accelerator pedal and therefore results into a (small) increase of the noise level.

However, the vehicles parked parallel to the curb contribute positively, by eliminating both the traffic flow and the pollutants and noise from the pavement, while also marking a relation of transfer between the roadside uses and the traffic flows, which is better integrated with the environment of the road [6].

Also, the parking places, both legal and illegal, are poles of attraction for private car owners, resulting into an increase of the traffic load and the consequent increase of the traffic noise and air pollution.

### 2.1.16 Longitudinal slopes

Upward-extending roads lead to higher fuel consumptions and, therefore, higher emissions.

### 2.1.17 Road paving materials – Road condition

In almost all of the city roads, the paving material used is asphalt for the road surface and concrete or marble slabs, or cube stones, for the pavement. In all cases, thermal accumulation is observed during the summer months, owing to the absorption of most part of the incident solar energy by the said materials. On the other hand, the sealing of the above surfaces increases the surface drainage of rainwater. In order to calculate the thermal accumulation of the paving materials, as well as of the construction materials used in roadside surfaces, the sun light reflectivity of a surface is used, as a percentage of the total incident solar energy. Alternatively, it is possible to use the reflectivity unit of surfaces, the Albedo value, which ranges from 0 to 1. In this sense, a surface with a high Albedo value ( $>0.75$ ) corresponds to light surface colouring, which reflects most part of the solar energy, while a surface with an Albedo value lower than 0.25 is dark and absorbs most of the incoming solar radiation.

Practically speaking, surfaces with low Albedo values can be warmer, even by 12 °C, compared to lightly coloured surfaces, with a high Albedo value, that are exposed to the same solar radiation. In this sense, roads and parking areas with dark-coloured materials, such as asphalt, absorb immense amounts of solar energy, heating the air around them and contributing considerably to the phenomenon of the urban heat island (UHI).

In general, it has been experimentally shown that the increase of the Albedo value by 0.1, results into a decrease of the road temperature by 2-5 °C [11].

The solar energy falling upon an opaque surface is partially reflected and partially absorbed by the said surface. The percentage correspondence between reflection and absorption is determined by the colour of the surface. In general, 15 percent of the incident solar radiation is, on average, reflected, while the remaining 85 percent is absorbed by the city's web. The reflected radiation (15 percent) is directed towards nearby surfaces, whereupon the reflection and absorption procedures continue, until the full absorption or the final reflection of the radiation.

The absorption of the solar energy causes an increase of the surface temperature, which in turn leads to heat exchanges that affect the temperatures of nearby surfaces and of the surrounding air.

### 2.1.18 Roadside facility construction materials

Generally speaking, the light colours on surfaces of roadside uses are more preferable in areas with a high h/w ratio, given that they also favour natural lighting, in addition to presenting reduced temperature absorption. Also, the thermal capacity of outer layers of walls affects the temperatures of the roads and of the uncovered areas of the city [5].

Most of the materials that are commonly used in construction works have a low Albedo value, in other words they tend to retain the solar radiation, instead of reflecting it back to space. The thermal energy entrapped is released slowly, in other words causes a slow progress of the cooling process. For example, for a day temperature of 30 °C, the temperature of the asphalt surface can rise even to 80 °C. With the sunset, begins also the slow release of the thermal energy that has accumulated during the day. Thus, while the cooling process of the asphalt surface begins, the air temperature begins to rise (UHI phenomenon).

### 2.1.19 Roadside equipment

#### *Surface-mounted*

- Wastebaskets: should be usable with food and beverage waste, paper waste, etc. Desirably, their material is fire-resistant and their construction prevents the entry of insects.
- Road signalling: the vertical signalling of the roads should follow common design principles, the signs should be conspicuous and readily identifiable and must change depending on the changing traffic needs.
- Pedestrian protection fencing: this is commonly used to prevent pedestrians from crossing the road at dangerous points, whilst preventing vehicles from climbing on exposed pavements.
- Low height posts: they are placed as necessary, in order to prevent the entry of vehicles, particularly in case the curbs do not provide adequate prevention. They are also used, whenever it is necessary to keep vehicles away from areas that are meant to be used primarily by pedestrians.
- Tree grates: they are placed on the ground, around the trunk of trees, on the one hand to allow the entry of oxygen towards the roots of trees and to protect the roots from vertical compression, on the other.
- Roadside light posts: they improve the general lighting level, for drivers and pedestrians alike, by also increasing the safety and visibility of the roads.
- Canopies and bus stops: they are used to delimit the area where passengers stand at bus stops, protected by the rain and the sun.

- Advertising posts and signs: they are used to attract the road users' attention, with the aim to promote one product or another.
- Phone booths: they provide privacy and relative sound insulation to persons wishing to make a phone call [12].

#### *Underground*

It includes all kinds of networks (water supply, sewage and rainwater drainage, power and telecommunication grids, gas and heating tubing, etc.)

#### **2.1.20 Artificial lighting**

Artificial lighting includes the lighting of roads, the traffic lights at junctions, the colour lighted posts of shops, and the lighting of important building and monuments, thus forming the aesthetic identity of the city and a climate of security for pedestrians during the night. The intensity of the lights, the relation between lit and dark areas, the relation of the illumination with the architectural pattern of the urban environment, as well as the influence of the lights of vehicles contribute to the isolation (or the non-isolation) of some roads during the night [13].

#### **2.1.21 Green elements**

The influence of green areas in the formation of the micro-climate is a function of the following properties:

- the high absorption percentage of solar radiation;
- the lower thermal capacity and thermal conductivity, in relation to the construction material of the buildings and open areas;
- the reduction of the temperature of the surrounding air, by means of transpiration;
- the reduced infrared radiation emitted;
- the reduction of wind speeds close to the ground;
- the retention of dust and pollutants by the surrounding air;
- the sound insulation it provides.

American researchers refer to differences in the air temperature, up to 8 °C, between implanted and non-implanted areas of the city. However, the influence of green areas is noticeable only in the directly adjacent areas, on the one hand, and such areas need to have a significant surface area (2000 sq.m. approximately – i.e. the size of a square), in order to function as oases [5].

#### **2.1.22 Population density**

Areas with a medium- to high population density (persons/hectare) function better, compared to areas with a low population density, with the proviso that certain conditions are fulfilled, relating

to the construction of the buildings and the distribution of activities. However, population densities that are significantly high, suggest an over-exploitation of the urban land and are accompanied by tall buildings, a compact and inflexible urban web and reduced open areas [6].

However, the high population densities result into high private car ownership patterns, which in turn entails a high percentage of bi-directional movements with private cars and, consequently, an increase of the level of air pollution and noise and thus, a reduction of the environmental quality of roads.

Recent research suggests that there is a correlation between the UHI phenomenon and the size of the population. Empirical studies and research efforts by Oke T.R., [Boundary Layer Climates, Methuen and Co.,1978, 1987, 1990] suggest that the temperature difference between the urban areas and the countryside is proportional to the population logarithm [14]

$$\Delta T (u-c) = 0.25 P/4u^{1/2} \text{ where}$$

$\Delta T (u-c)$ : temperature difference between the urban area and the countryside;

P: population logarithm;

u: wind speed at a level of 10 metres.

#### **2.1.23 Means of transport**

Currently, due to the lack of proper planning for public transportation, the movements in the majority of Greek cities are effected using private cars. It is, on the contrary, necessary to discourage the dependence on private means of transport, by adopting effective parking and pricing policies. The concerted planning of places of origin and destination can lead to the development of public transport means and facilities for pedestrians and cyclists, while it is also considered necessary to include non-polluting transport means into the overall system, so as to reduce the consumption of fossil fuels and the consequent emission of pollutants [15].

It is indicatively pointed out that, with a 50% capacity, the consumption of energy per bus passenger kilometer is 5 times lower than that of the private car. Also, the necessary road surface is reduced in proportion to the number of passengers, while the discharge capacity of the road is increased, particularly when there are exclusive use lanes for public transport means.

#### **2.1.24 User safety**

It has been statistically shown that the most vulnerable users of the road are pedestrians, cyclists and motorcycle riders. It has been however claimed that the statistics of accidents provide a false picture of reality. The number of accidents is small because, on the one hand, not all accidents

are registered officially and, on the other, a lifestyle not compatible with the notion of the viable city has been chosen. The number of accidents would be significantly higher if the residents, despite the risks inherent in almost all of the urban roads, insisted on walking, using the bicycle and, in the case of children playing on the road [15].

Based on figures derived from the annual report of the road safety observatory of the Technical Chamber of Greece, 20 percent of the accidents is observed at level junctions. This is because the dramatic increase of the road infrastructure in Greece has not been accompanied by the necessary arrangement of accesses and level junctions, while in other cases, the influence of the new road projects has not been assessed with regard to the mobility of pedestrians. Another reason for this observation is the fact that the construction of certain facilities (trade centres, cinemas, sports centres, etc.) are a pole of attraction for movements. The diagramme following depicts that almost half of the fatal road accidents (42%) are observed on urban roads (2003 figures, [16]).

Undoubtedly, the accidents are relate to on-road behaviour, which can be controlled, to a large extent, by the design of the road. Th geometrical design of roads, particularly of urban ones, can achieve a reduction of accidents and a safe and smooth co-existence of the various road users. Road safety and rehabilitation are two inter-dependent notions. The rehabilitation of a road should aim at reducing pollution, as well as at improving the quality of life conditions, both on the road and for roadside uses [15].

### 2.1.25 Cleanliness and hygiene

Apart from the wastebaskets mentioned above as surface road equipment elements, as well as the rainwater drainage networks included in the underground equipment, the cleanliness and the hygiene relate to the system for the storage of waste that is produced on a daily basis along the roadside uses, as well as to the extent to which the wastebaskets are integrated smoothly into the environment of the road.

### 2.1.26 Maintenance, modernisation and re-use of historical resources

Monuments, preservable buildings, historical centres are all significant elements for preserving the physiognomy of a locality. For a city aiming to be considered as having a high environmental quality, the building shells should be treated as a valuable resource, and their cultural role, as repositories of historical memory, should be recognised. It is therefore necessary to maintain, modernise and re-use these buildings. However, the current regime, of high bpl values, leads to the

demolition of old shells, while the rehabilitation and re-use of the existing building should be encouraged, in relation to the construction of a new building (lower building permit issuance costs, tax reliefs, low loan interest rates, etc).

Preventing the irrational expansion of the urban space will contribute to the re-use of old building shells.

### 2.1.27 Land values

Until recently, the parameters mentioned above affect directly or indirectly the environmental quality of roads. The land values, as well as the urban zone rates, the commercial value coefficients, etc. (financial indices) of a given area are affected also by the environmental quality of its roads.

In this sense, plots facing roads that fulfill the parameters contributing to the said environmental quality can have a higher value in relation to other plots, located within environmentally degraded areas.

## 2.2 The case of roads in Heraklion

### 2.2.1 Methodology

It would be time-consuming and would not serve any specific purpose to examine the environmental parameters for all the roads within the urban complex of Heraklion. Therefore, we selected some representative roads, located at different areas of the urban complex of Heraklion, characterised by different urban planning parameters, and having different orientation and, hence, different bio-climatic parameters, different traffic parameters, and different technical characteristics, as well as different combinations of the above. The representative character of the cases examined aims to reflect, to the maximum possible extent, all the cases observed in the city, in terms of both the description of the current situation and the proposals for improvement. The map below (fig. 1) depicts the urban complex of Heraklion and the roads selected.

First, field work was conducted, related to site measurements, using tape-measure, to determine the widths of the road surfaces and pavements, where existing, as well as to record the number of storeys at roadside uses and, hence, to determine the prevailing building heights for each road and then to calculate the h/w ratio (= prevailing building height / interim distance, where the distance is considered as the sum of the road surface width (road surface + pavements), including border spaces, where applicable). We also recorded the surface equipment of the roads, the paving materials and the age of the road surface, as well as the construction materials used

at roadside facilities, the existence of artificial lighting, the cleanliness and hygiene, the existence of historical and cultural buildings and, finally, the plants and green elements. Field work includes also photo-shoots, aimed at better documenting the existing situation of the roads studied.

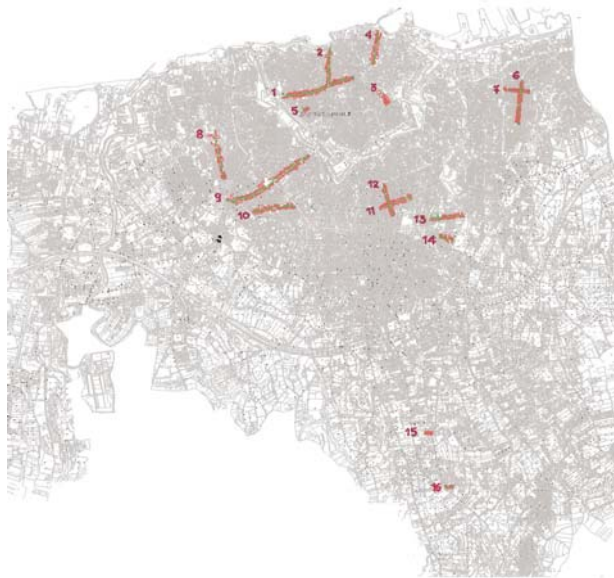


Fig. 1: Location of the roads examined

Data related to the atmospheric pollution of the urban complex of Heraklion was derived from the MSc dissertation of the Department of Chemistry of the University of Crete, related to measurements during 2002-2003.

Noise data was derived from measurements of the Mechanical Engineering Department of the Technological Educational Institute of Crete, gathered in the context of a diploma dissertation.

The traffic department of the Technical Works Directorate of the Municipality of Heraklion provided us with data related to traffic parameters, based on the General Study on Transport and Traffic for Heraklion, Crete: "Final Report and Analysis of the Current Situation", conducted by Doxiadis Associates.

The "old town office" of the Municipality of Heraklion provided us with data related to the rehabilitation of the area within the Venetian wall, based on the Urban Rehabilitation Study conducted by the collaborating agencies PHILON & PHILOPOLIS.

The Urban Planning Directorate of the Municipality of Heraklion has provided data related to the urban planning parameters of the roads examined.

The data related to traffic accidents were derived from the Road Traffic Police of Heraklion and from local press publications.

The data related to land values, zone rates, commercial value coefficients, etc. were derived from Tax Offices A & B of Heraklion.

## 2.2.2 General Parameters

### 2.2.2.1 Air pollution

The concentrations of the main air pollutants (CO, NO<sub>x</sub>, SO<sub>2</sub>, O<sub>3</sub>) in the city are recorded on a constant basis, since the end of 1990, by an air pollution measurement station of the Region of Crete. These measurements, the results of which are analysed below, cover the period from November, 2000 to March, 2003.

Thus, CO concentrations are characterised by an intense seasonal variation with peak values (400-750 ppbvs) during the winter months and minimum values (200-300 ppbvs) during the summer. The winter peak is due to the intensification of combustions (for the heating of buildings) and to the deterioration of the operating conditions of vehicle engines (cold starts).

A corresponding seasonal variation is characteristic of SO<sub>2</sub> concentrations, also, of which the oil combustions (for heating buildings, as fuel for diesel engines, etc.) constitute the main emission source. Thus, the maximum concentrations (4-9 ppbvs) are observed during the winter months and are significantly lower than the maximum limits specified for the protection of human health (22 ppby, as the average annual concentration according to the common ministerial decision 99/1087).

Based on observations of the 24-hour variation of the above-mentioned pollutants, CO concentrations maintain the same 24-hour variation tendency, something that suggests the main emission source (vehicle movement). The main emission source of SO<sub>2</sub> is the combustion of oil for the heating of buildings.

O<sub>3</sub> concentration values are the ones derived from measurements during 1990-1999, which ranged from 30 to 70 ppbvs, with the maximum values taken during the summer months and the minimum during the winter months, something that reflects the photochemical origin of the pollutant.

Based on the 24-hour variation of CO and NO<sub>x</sub> concentrations, the more intense effect of the movement of vehicles on the concentrations of these pollutants is observed during the morning rush hours (7 to 9 am).

The role of the local NO<sub>x</sub> emissions to the concentrations of O<sub>3</sub> (NO + O<sub>3</sub> NO<sub>2</sub> + O<sub>2</sub>) is obvious in the 24-hour variation of the latter. Their minimisation during the morning hours is typical of the urban centres and the morning traffic peak.

### 2.2.2.2 Noise



Generally speaking, based on measurements carried out in the context of a BSc dissertation of the Mechanical Engineering Department of the Technological Educational Institute of Crete entitled "Noise in the urban environment. Measurements (processing, conclusions, proposals) using noise meters at roads and urban junctions of Heraklion" (in Greek), it has been shown that:

- Trunk roads leading into and out of the city centre present the highest noise levels recorded, i.e.  $78 \text{ dB(A)} < \text{Leq} < 86.5 \text{ dB(A)}$ ;
- City centre roads that are characterised mainly by commercial uses were measured at  $76 \text{ dB(A)} < \text{Leq} < 81 \text{ dB(A)}$ ;
- In residential areas close to the city centre that are characterised by complexes of connecting roads, the measurement range was  $76.2 \text{ dB(A)} < \text{Leq} < 81.6 \text{ dB(A)}$ ;
- In residential areas away from the city centre, with collecting roads without significant traffic loads, the measurements were:  $66.7 \text{ dB(A)} < \text{Leq} < 71.9 \text{ dB(A)}$ ;
- In local roads, many of the measurements taken were below the  $60 \text{ dB(A)}$  limit.

#### 2.2.2.3 Building permit limits

Within the urban complex of Heraklion, the applicable building permit limits range from 2.80 in the old town to 0.60 in areas of recent expansion (areas inhabited by residents with very high incomes, requiring increased land values and infrastructure works, while also presenting the problem of significant distances from the locations of common-use and social facilities and requiring movements using, almost exclusively, the private car, as the means of transport).

The interim areas, located between the new expansions and the historical centre, with a bpl of 1.80, 1.20 and 0.70, present a relatively economical alternative, in terms of land costs and infrastructure. However, they do provide the necessary social environment and are not burdened by the problems of dense construction patterns. On the contrary, at least part of their construction volume presents problems in terms of insolation, lighting, direct view and isolation.

The thematic map below (fig. 2) shows the building permit limits currently applicable in the urban complex of Heraklion.

#### 2.2.2.4 Construction pattern

The construction pattern of the urban complex of Heraklion is continuous in the city centre and in surrounding areas (something implying increased mutual shading, decrease of the visibility of the skydome and of the building ventilation conditions, as well as retention of air pollutants), becomes free on all sides in some parts of old city expansions,

which present better insolation and ventilation conditions and leave more space for plants and, lastly, becomes free in the areas of the new city expansions.

The thematic map below (fig. 3) shows the current building pattern in the urban complex of Heraklion.

#### 2.2.2.5 Parking

Currently, the parking problem, particularly within the Venetian wall areas is one of the principal causes for any disturbance in the traffic of vehicles. During the last years, the number of curb-parallel parking spaces has decreased significantly and has not been counter-balanced by the creation of three additional municipal parking areas, given also that the demand for parking spaces has in the meantime increased.

In total, there are about 6,500 legal parking places in the central area (within the Venetian wall), of which 1,300 are located beyond the road limits (30 percent).

Around 10.00 am, an accumulation of vehicles is observed, exceeding 10,000 private cars, while in the afternoon, around 7.00 pm, the number of vehicles exceeds 8,000. Therefore, more than 3,500 vehicles are parked illegally.

Because of the fact that illegal parking is unevenly distributed in the old town, the parallel parking capacity of which is inadequate. Consequently, the movement of vehicles is seriously impeded.

At the 12 parking stations (both open and covered), the exchange of parking place usage is very low, with 45 percent of parking demand extending beyond 8 hours of stay.

As pertains to illegal parking, it has been observed that more than 60% of the vehicles are parked for one hour, and a mere 20% are parked for 2 hours.

Only 1% of the total number of movements (internal – external) of the citizens of Heraklion (165,000 and 45,200, respectively) ends up in parking stations. Therefore, parking spaces are free in Heraklion, despite the fact that they are totally inadequate.

There is no systematic policing of illegal parking and, therefore, the latter tends to acquire the characteristics of free parking [13].

#### 2.2.2.6 Population density

Below there is a thematic map (fig. 4) which depicts the population density of the urban complex of Heraklion. Despite the fact that one would expect increased population densities inside the Venetian wall areas, mainly because of the high bpl values, this is indeed true only in small areas of the city centre that are inhabited mainly by economic

immigrants, as well as financially poor groups of the city's population.

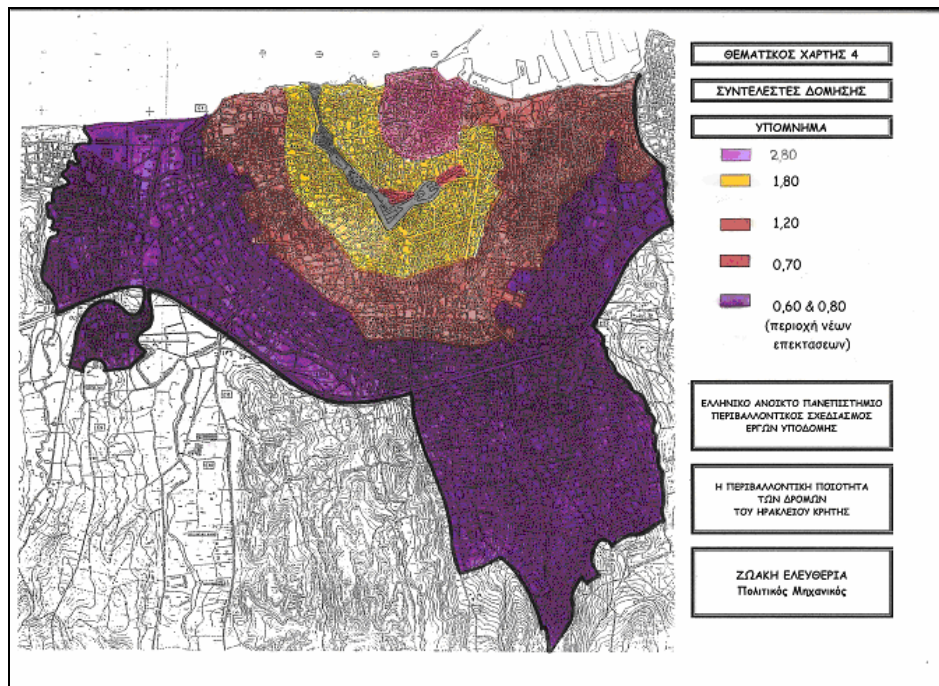


Fig.2: Building Permit Limits

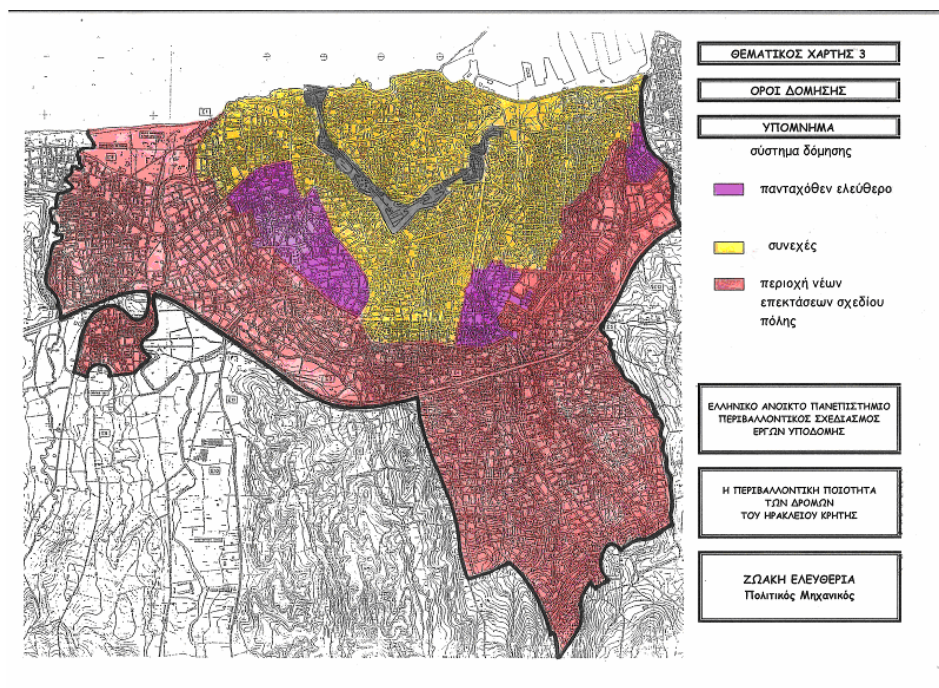


Fig. 3 : Building Pattern

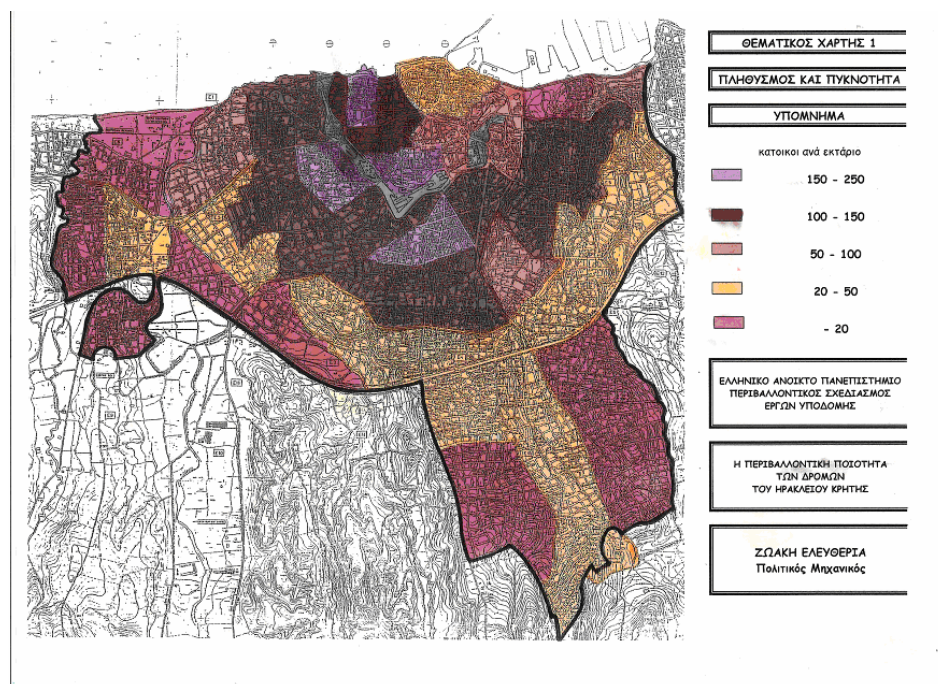


Fig. 4 : Population density

In the remaining areas of the centre, where the main functions are trade and services and residences are only a secondary function, the population densities are halved, while in the expansion areas, both new and old, the population density is significantly decreased.

#### 2.2.2.7 Transport means – Public transport

In many cases, the organisation of bus lines and routes is effected empirically. Thus, there are frequent deviations from the planned timetables, while 100-seat buses are not always utilised profitably along the bus routes and during the hours when they are needed more. The frequency of some bus routes is so low, that they seem to function as mere suburban routes.

The maximum capacity of the routes often exceeds the legal capacity of the vehicles, something that points to the need to increase their frequency (i.e. reduce the time-distances) during the peak hours.

Obvious is also the lack of a peripheral route interconnecting the areas outside the city centre. This fact outlines the lack of a suitable ring road connecting the out-of-centre areas.

The compulsory use of the city centre by all bus routes is deteriorated by, and in turn deteriorates, the traffic conditions.

#### 2.2.2.8 Road accidents

Finally, as pertains to the causes of road accidents within the urban complex of Heraklion, involving drivers by 80-90 percent, these are:

- Lack of driver attention 39.4%
- Violation of priority rules 29.9%
- Trespassing of “STOP” road signs 9.3%

- Illegal overtaking 4.3%
- Trespassing of the red traffic light 0.9%
- Drunk driving 0.7%
- Excessive speed 0.6%
- Slippery road surface 0.5%
- Violation of safety distances 0.4%
- Trespassing of one-way road signs 0.2%
- Deficient braking system 0.04%
- Other causes 13.8%

Based on estimations of the road traffic police of Heraklion, around 15 percent of the accidents occurring in the urban complex of Heraklion are never reported to the police, either because the damage caused to the vehicles is small, or because the persons involved suffer minor injuries and do not wish to sue one another.

#### 2.2.3 Indicative development of the individual parameters of one of the sixteen roads examined – Kapodistriou str.

- General: it is located in the area of Atsalenio and constitutes a residential area, with a few local shops.
- Road length: 310 m
- Free spaces: no
- Insolation – Sun protection

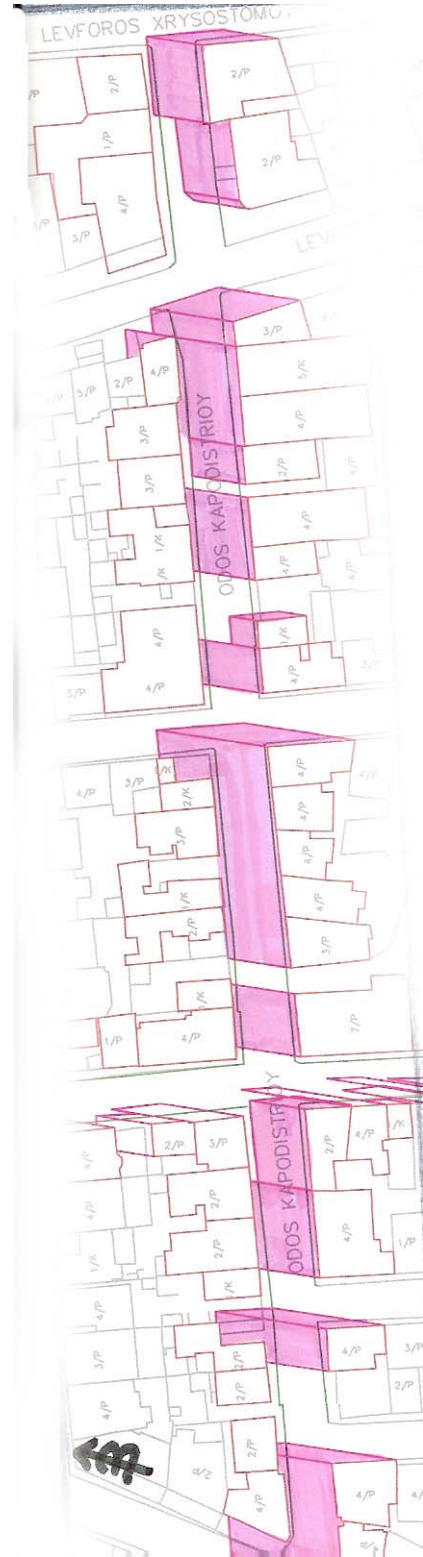
Comment: the road is shaded along its entire length during the winter months, when insolation is desirable, while, during the summer months, when shading is a factor of thermal convenience, it shaded only over a small part, south of the road.



*Fig. 5 : View of the road from the East, with relatively recent buildings and average trees*



*Fig. 6 : Angle parking, along the northern pavement, a fact facilitated by the width and direction of the road, thus economising space for the parking of more vehicles*



*Fig. 7 :Insolation diagram, 21 December, 12.00 pm*



Fig. 8 : Sun protection diagram, 21 June, 12.00 pm

- Ventilation – wind protection: based on wind data derived from the airport of Heraklion, the prevailing winds of the area are light to moderate, NW, N and S, in other words blowing vertically to the direction of the road,

something that facilitates the accumulation of pollutants in the area.

- Building permit limits – building heights: 1.80
  - prevailing building height: 12,00 m
  - maximum building height: 21,00 m
- Construction density and pattern: continuous (problems in terms of insolation, lighting, direct view with increased mutual shading, reduction of the skydome visibility and of the buildings' ventilation conditions, as well as retention of pollutants).
- Road orientation – cross section: NE-SW (70° in relation to the North). The road width is 9.00 metres.
- Building forms: On both sides of the road, the buildings are older constructions, which have been thoroughly maintained, almost in their entirety. A few buildings have been constructed recently.
- Border spaces: no.
- Pavements: The width of the pavements varies. The following widths were measured upon our on-site visit (northern pavement – road surface width – southern pavement): 1.0-9.0-1.0 1.5-9.0-1.0 1.5-9.0-1.5.
- Height to width ratio: for the above-mentioned pavement and road surface widths, and for the prevalent building height (12.00 m) the following h/w ratios are calculated: 1.1 1.04 1.0.
- Traffic composition: mainly private cars, taxis and motorcycles.
- Parking places and patterns: along most part of the road, parking is parallel to the curb on both sides, while along a small part on the West, parking is angled along the northern pavement.
- Longitudinal slopes: 2 percent.
- One-way, two-way road: one-way road, with a W-E direction.
- Road paving materials – road surface condition: the road surface is asphalt, while the pavements on both sides of the road are covered with square concrete slabs. The condition of both the road, and the pavements, is satisfactory.
- Roadside facilities construction materials: concrete walls, with light colours (white, grey, or beige).
- Green elements: on both sides of the road, there are trees with an average height, while the green areas are completed with flower pots on the balconies of the buildings.
- Population density: as is depicted in Fig. 4.11, the road is located in an area where the population density is about 150-200 inhabitants/hectare.

- Means of transport: private cars and motorcycles, with taxis and buses moving along Knossou ave. and Ionias ave., East and West of the road, respectively.
- Cleanliness and hygiene: wastebaskets covering the needs of the road users.
- Land value
  - zone rate: 1800
  - plot coefficient: 1.00
  - plot value coefficient: 1.80
  - commercial value coefficient: 1.00

**2.2.4 Processing of the data examined for each particular road**

**2.2.4.1 Insolation – Sun protection**



Fig. 9: Insolation

Sixty-two percent (62%) of the roads examined are fully shaded during the winter months, either because of their orientation, or because of the height and location of buildings on both sides of the road, the width of the road or a combination of all these factors.

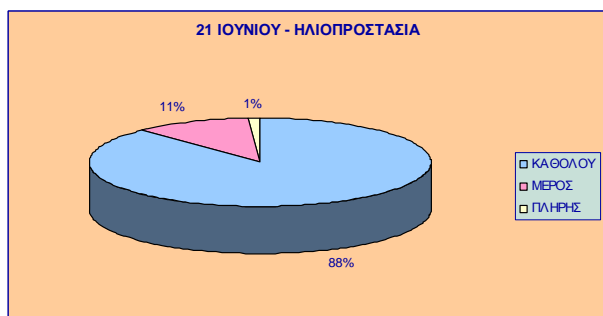


Fig. 10: Sun protection

Eighty-eight percent (88%) of the roads examined are fully sunlit during the summer months, either because of their orientation, or because of the height and location of buildings on both sides of the road, the width of the road or a combination of all these factors.

It is, therefore, an urgent need to shade these roads during the summer months, utilising means and techniques, as presented below.

**2.2.4.2 Ventilation– Wind protection**

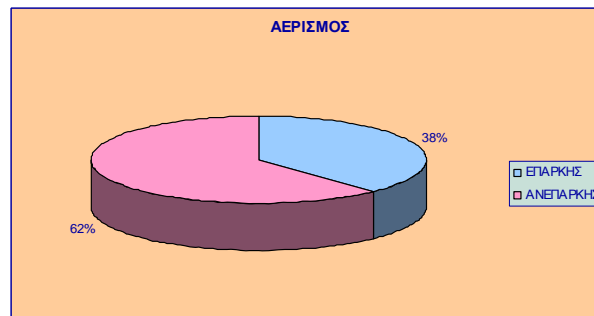


Fig. 11: Ventilation

Thirty-two percent (32%) of the total length of the roads examined are ventilated sufficiently, owing to their orientation, which matches (perfectly or closely) the direction of the prevailing winds. Seventy percent (70%) of the said length can present phenomena of channelling, with eddies and swirls and, for this reason, it is considered necessary to find solutions in order to address this problem.

Most of the roads in the urban complex of Heraklion have a N-NE orientation, given that, as a historical city, Heraklion follows the radial system of roads, i.e. a pattern that favours the ventilation of large road sections, during most days of the year. This orientation coincides with the direction of the winds prevailing in the area.

The remaining road sections favour the entrapment of pollutants, a problem which can nevertheless be prevented with the use of solutions and techniques presented below.

**2.2.4.3 Building heights**

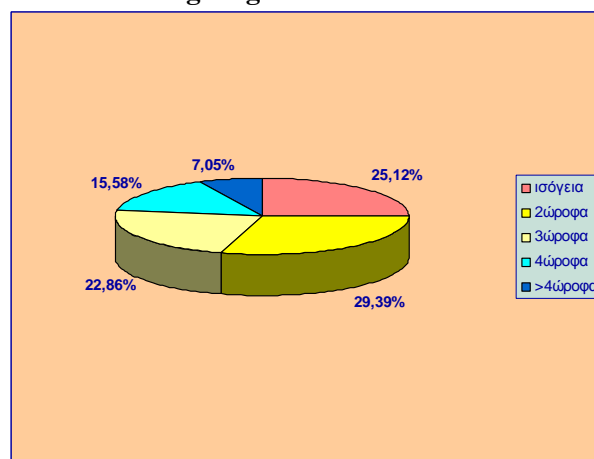


Fig. 12: Building heights

The buildings on both sides of the roads examined are two-storey (29.4%) and single-storey constructions (25.1%). In other words, more than half of the buildings (54.5%) have a height below 6.00 meters.

**2.2.4.4 Height/width ratio**

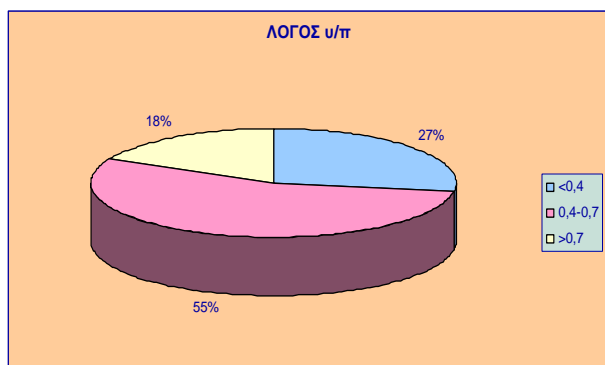


Fig. 13: h/w ratio

Despite the fact that 82% of the total length of the roads examined has a h/w ratio <math><0.7</math>, as shown above, the road sections in question do not present ideal bioclimatic conditions. This can be explained by the fact that the literature on the conditions of environmental quality in relation to the h/w ratio focuses more on the buildings on either sides of the road, than on the road itself.

The existence of border spaces in areas built using either the "open on all sides" or "open" construction pattern increases the distances between the buildings and provides better conditions of hygiene and safety and visual and thermal convenience, for the users of both the road and the roadside facilities.

**...in relation to the building permit limits**

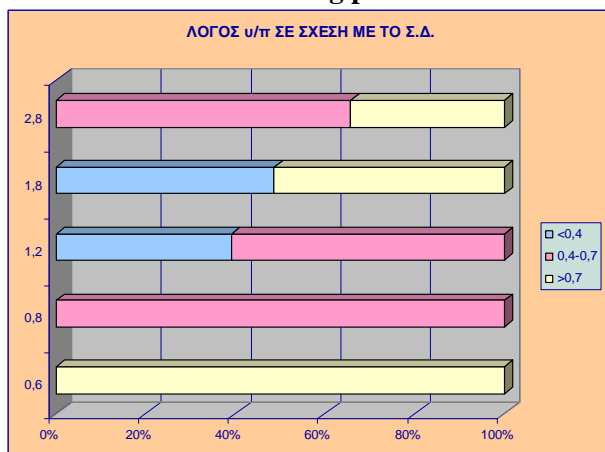


Fig. 14: h/w ratio, in relation to the building permit limits

As one would expect, areas with a high building permit limit (bpl factor of 2.8 and 1.8, respectively) exceed the set h/w ratio of 0.7, as happens also in areas of new expansions, in which small properties and illegal constructions prevail, regardless of the building permit limit which has not been respected. It is known for these areas, to "have been built first, and thereafter planned in urban terms".

High bpl values (2.8 for the central area and 1.8 for its periphery) have been adopted to a large

extent. It is also commonplace in some plots, the constructions built before the enactment of these bpls (i.e. before 1978) to exceed the bpl and, in some cases, remarkably.

**...in relation to the building system**

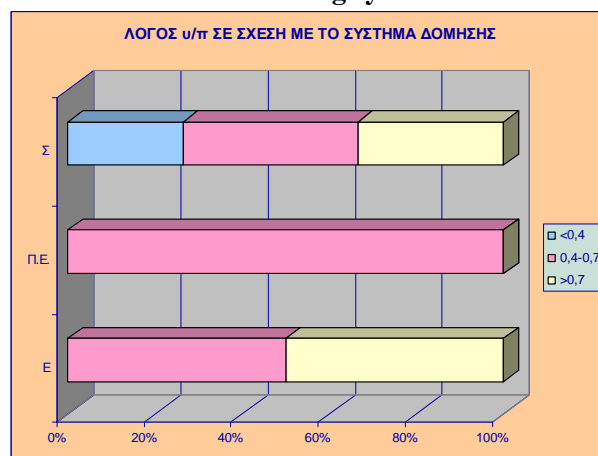


Fig. 15: h/w ratio in relation to the building system

As pertains to the building system, values above 0.7 for the h/w ratio, are remarked in the continuous building system (narrow roads, especially in the historical part of the city and/or tall buildings) and in the areas of illegal constructions (over-exploitation of the private spaces to the detriment of public space).

The continuous building system, typical of the central area and its greater periphery, results into the entrapment of air pollutants and noise. The scaled arrangement of the last storeys of buildings, in areas with such a pattern, partially mitigates the above problems and positively affects the insolation on the road.

Both the "open-on-all-sides" construction pattern of the old city expansions, and the "open" construction pattern of the new expansions, together with the relatively big intervals between the buildings allow for better insolation conditions, as well as for visual and thermal convenience, compared to the central area.

**2.2.4.5 Longitudinal slopes**



Fig. 16: Longitudinal slopes

In the roads examined, and by extension in the urban complex of Heraklion, the relief is



smooth, with slopes ranging between 0 and 2 percent for 50% of the roads and a mere 26 percent of the roads presenting intense slopes (>4%).

Therefore, pedestrian movements are favoured, as is also cycling. Furthermore, the production of air pollutants and noise from vehicles is not increased.

#### 2.2.4.6 Means of transport

Owning a private car was once an indication of prosperity and rise of the living standards. Nowadays, the widespread use of the private car is beyond any control, given that the purchase of a car is affordable for all. Thus, all of the roads examined and, by extension, in the entire city, the majority of journeys are made by private car, including short distance journeys that could otherwise be made on foot.

A parameter contributing to the excessive use of the private car is the problematic public transport network. In many cases, the organisation of bus routes and itineraries takes place on a rather empirical basis, resulting in frequent deviations from the scheduled itineraries.

Even in areas covered sufficiently by the public transport network, there is lack of sheltered bus stops, that are safe for awaiting passengers. Also, many areas, especially in the new city expansions, are not included in the bus route network.

Finally, the compulsory use of the city centre by all the bus routes is an obstruct to, and is obstructed by, the general traffic conditions.

Obvious is also the lack of a peripheral route connecting areas outside the city centre, something that outlines the lack of a suitable peripheral road axis connecting the out-of-centre areas.

#### 2.2.4.7 Road network - Parking

As is evident also in the roads examined, most collecting roads of the urban complex of Heraklion, with very few exceptions in areas of the historical centre and in the areas of the new city expansions that "were first built and then planned", do indeed have the necessary geometrical characteristics, with a road surface width ranging from 8.00 to 10.00 m.

The local roads bear small traffic loads, are characterised by small lengths and widths and, in many cases, are blind alleys, mostly in the areas of the new expansions, south of the city.

Another characteristic of these roads is their intensely varying width, as well as the phenomenon of non-opened sections, something that negatively affects the city's accessibility.

As pertains to parking, it is remarked that, with very few exceptions, it takes place on the roadside, either on the one, or on both sides, both in the centre and in the surrounding areas. In some

cases, parking is permitted and in some other cases, it is not. Problems related to parking are remarked mainly along the road axes of the historical commercial centre, making the already problematic conditions of traffic even more difficult.

Illegal parking includes also the cases of double parking, especially in areas of the city centre, parking on pavements and within small distances from intersections, with or without traffic signs, resulting in reduced road traffic capacity, reduced driver and pedestrian visibility, occupation of pavements and pedestrian crossings, etc.

#### 2.2.4.8 Pavement widths

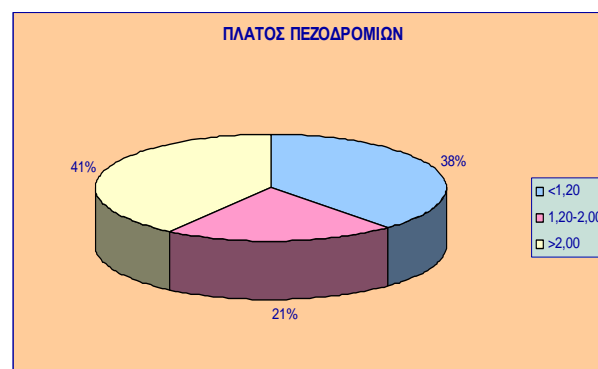


Fig. 17: Pavement widths

Thirty-eight percent (38%) of the roads examined, either lack a pavement or have pavements of small widths (<1.2 m), that do not suffice for two persons simultaneously using the pavement.

Pavements with a width of more than 2.0 m are found in areas with the "open on all sides" construction pattern, while pavement widths ranging from 1.2 to 2.0 m are found in areas of the city centre that have been recently reformed.

The design and construction problems that hinder the movements of pedestrians are categorised as follows:

- Poor workmanship in the construction of the pavements (irregularities, poor transverse slope, potholes, smooth surfaces);
- Poor workmanship in the construction of the ramps;
- Poor workmanship in the construction of the kerbs (unacceptable height);
- Stairways on pavements;
- Small size of traffic islands;
- Insufficient lighting;
- Non-formed pavements;
- Big longitudinal slopes;
- Insufficient pavement surface in relation to the movements (load) of pedestrians.

#### 2.2.4.9 Vegetation

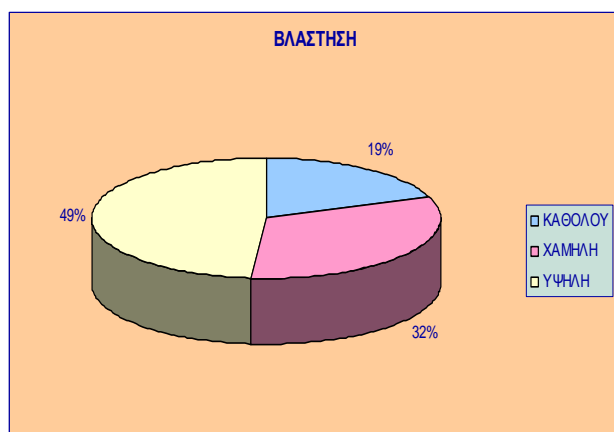


Fig. 18: Vegetation

In about 20 percent of the roads examined, there is total absence of vegetation, while in 49 percent of the roads, where the vegetation is characterised as high (tall or densely arranged trees), the vegetation of border spaces and balconies has also been taken into consideration (areas with a low bpl and open building pattern - private properties).

Generally speaking, the trees are absent from most of the city's roads inside the Venetian walls, while the existing trees, especially along roads that have been recently reformed, have been planted recently or are of a small size.

#### 2.2.4.10 Road surface materials and condition

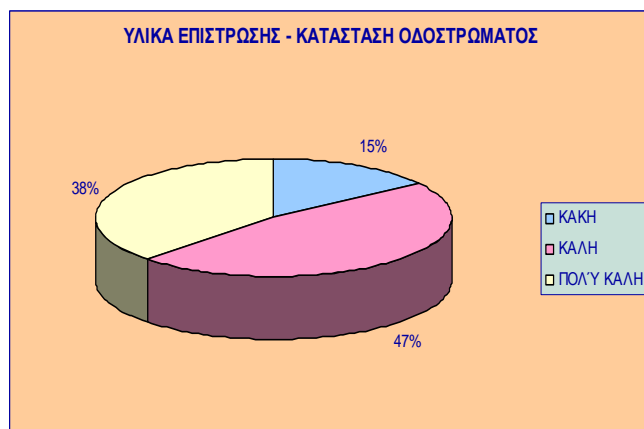


Fig. 19: Road surface materials and condition

Generally speaking, in a very small percentage of the roads examined (15%), the condition of the road surface is characterised as poor, mainly due to lack of maintenance, while in the remaining 85%, the condition is characterised as good or very good. Also, the poor condition of the road surface reflects problems in the underground equipment of the road (water supply and drainage networks, telephone lines, etc.).

#### 2.2.4.11 Traffic signs

In most part of the length of the roads of the urban complex of Heraklion, there are practically no signs, both for traffic regulation and for informative purposes. This, in turn, affects both the road safety and the intensification of the phenomenon of additional courses and results in the overloading of the road network with vehicles and the increase of noise and air pollution, as well as of energy consumption.

### 3 Interventions

This paper has presented the parameters that cause problems to the environmental quality of roads in the urban complex of Heraklion. Following this, we present some indicative interventions, which could be undertaken by the state or even private entities, and could, indirectly or directly, help to improve the environmental quality. The interventions proposed relate to the user of the road (pedestrian, cyclist, passenger of public transport means, vehicle driver - even though effort is being put in reducing the latter to the minimum extent possible), focusing on functionality, safety and, of course, convenience and aesthetic value.

#### 3.1 General interventions

Classification of the city's road network, with the creation of distinct rings aimed to protect the neighbourhoods from through traffic and prevent the aimless passage of vehicles through the city centre.

Utilisation of appropriate signs (traffic, informative), both horizontal and vertical, in conspicuous places, with the aim to prevent additional courses and to increase the level of road safety, whilst reducing traffic loads.

The reduction of the traffic loads and movements into and out-of the city centre can be achieved also with the decentralisation of certain functions (public service locations, shops). The creation of two urban planning centres (i.e. eastern and western), a matter discussed for years, must now be implemented.

Replacement and maintenance of underground public utility infrastructures, underground deployment of the now overhead power grids and rebuilding of the road surface, though not necessarily with asphalt. The use of environment-friendly materials (stone or concrete blocks, stamped and coloured concrete or even stamped and/or coloured asphalt surface), in addition to providing environmental upgrade (light-coloured materials, higher reflectivity), will also improve the aesthetic value of the road [15].

Implementation of the scaled arrangement of the last storeys of buildings (positively affecting

sun-lighting, ventilation and dispersal of air pollutants) and of pilotis on the ground floor of new buildings (positively affecting the ventilation of both the buildings and the roads).

Installation of technical equipment (wastebaskets and wastebins, lighting elements, etc.) in roads lacking thereof.

### 3.2 Interventions for pedestrians

Widening the existing pavements, so as to enable the convenient crossing of two pedestrians, including the planting of, and the provision of technical equipment for, the pavement (1.50-2.0 m).

Discouraging the use of the private car, by reducing the parking places, increasing the cost of parking and imposing more restrictive time limits for parking.

Adoption of measures aimed at reducing traffic speeds inside the city and, especially, in local roads [17].

Improving safety, by rebuilding the destroyed parts of pavements and by ensuring anti-slippery surfaces and homogeneity all over the pavement, as well as by ensuring adequate lighting during night hours, without intense changes between light and dark [18].

Creation of pedestrian streets connecting points of historical and cultural interest within the Venetian fortress area of the city and giving priority to pedestrians, at the points of intersection with vehicle traffic roads, through the provision of "green waves" for pedestrians (continuous movement of an average pedestrian with normal walking pace) [7].

Conversion of two-way collecting roads to one-way roads (improvement of road safety through reduction of traffic flow collision points, elimination of head-on collisions and improvement of visibility at intersections).

Planting of deciduous trees and bushes on the eastern pavement of roads with a N-S direction and on the southern pavement of roads with a E-W direction, so as to ensure shading during the summer months..

### 3.2 Interventions for cyclists

The bicycle may be one of the most effective solutions for the problem of inadequate movement and parking areas, in the 21st century city, given that it still guarantees independence of movement.

Introducing the use of the bicycle and restructuring the road space are two closely interconnected aims. The one is a prerequisite for the other. Unless the road space is made beautiful, attractive and cyclist-friendly, residents will continue to choose cars or motorcycles, i.e. means of transport that cannot be categorised as

environmentally sound, regardless of the classification criteria used. On the other hand, unless the citizens start to use the bicycle for some of their journeys, there will be no suitable awareness, that would urge the authorities to proceed with the implementation of the city's reformation works [15].

Based on the above, bicycle use in the urban complex of Heraklion, an area with favourable longitudinal slopes and climatic conditions, is achievable by:

- Rebuilding the road surface with the materials mentioned above;
- Allowing the use of pedestrian zones to cyclists;
- Construction of bicycle parking areas at the public transport terminals, thus allowing combined transport schemes;
- Utilisation of buses with bicycle carrying capability;
- New lines on principal and collecting roads, creating cycle lanes;
- Replacement of traffic signalling at intersections, ensuring priority for cyclists;
- Creation of traffic loops in the city's historical centre, with privileged bicycle traffic [20].

### 3.3 Interventions for public transport

Creation of new routes in areas with poor or no public transport coverage.

Covering the needs of the city centre and neighbourhoods with minibuses and operation of transfer stations at the city's gates of entry into the historical centre.

Co-ordination of the various routes and transport means, so as to facilitate transfers.

Establishment of attractive public transport timetables.

Full and precise information at bus stops and inside public transport vehicles for itineraries and other network facilities.

Elaborating on the possibility to use environment-friendly fuels (bio-fuels, gas, etc.).

### 3.4 Public and private initiatives

The interventions mentioned above relate mainly to the government, at the local and/or central level. However, without private initiatives, no intervention is eventually feasible. Familiarising with the use of the bicycle or of public transport, or moving on foot, by simultaneously reducing the use of the private car, depends on the citizens, as does also the planting of border spaces in the areas built with the "open on all sides" pattern or of balconies on multi-storey buildings, and the use of environmentally sound materials for developing roadside uses. Finally, it is up to the users of roads

to preserve the environmental quality of the roads in the city of Heraklion.

### 3.5 Effect of interventions on parameters of environmental quality

Almost all of the above interventions aim, directly or indirectly, at discouraging the use of the private car in the city's roads and by affecting some of the environmental quality parameters in the city, as shown on the following table (table 2).

### Conclusions

It is obvious, both from analysing the current situation of environmental quality in the roads of the urban complex of Heraklion and from the

proposals proposed, that there is a need to create a Geographic Information System.

The undoubted complexity and interaction of the information issues that are evoked by the modern needs for urban, traffic, spatial arrangement and environmental planning, can easily be addressed with the creation of a database, which could contribute to the qualitative improvement of research in issues pertaining to environmental design and, simultaneously, allow for a diachroning information and control of the factors making up an environmental policy. The material that is needed for creating the said database, is indeed available. What remains to be done is the processing, updating and illustration of this material in the form of maps or charts of quantitative data, as well as its continuous updating.

	S u n l i g h t	S u n p r o t e c t i o n	V e n t i l a t i o n	W i n d p r o t e c t i o n	N o i s e	Ai r p o l l u t i o n	V i s u a l d i s t u r b a n c e	Tr a f f i c l o a d s	U s e o f v e h i c l e s	S a f e t y	Aesth etic Value
Classification of the road network					⬇	⬇		⬇			
Road signs – Adjustment of road signalling								⬇		⬆	
Decentralisation of central functions					⬇	⬇		⬇			
Network repairs - rebuilding of roads							⬇				⬆
Penthouses –pilotis	⬆		⬆			⬇					
Installation of equipment						⬇					
Widening of pavements									⬇	⬆	
Vehicle parking policies									⬇		
Speed reduction									⬇		
Reconstruction of pavements										⬆	⬆
Pedestrian streets										⬆	
One-way roads									⬇	⬆	
Planting		⬆		⬆	⬇	⬇					⬆
New bus routes					⬇	⬇		⬇	⬇		
Minibus					⬇	⬇		⬇	⬇		
Facilitating transfers					⬇	⬇		⬇	⬇		
Denser itineraries					⬇	⬇		⬇	⬇		
Information on bus facilities					⬇	⬇		⬇	⬇		

Table 2: Effect of interventions on parameters of environmental quality

## References

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