A WIRELESS SENSOR NETWORK DESIGN TO TEST TEMPERATURE VARIATIONS OF URBAN CANYONS THROUGH FLUENT MODELS

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Abstract

This paper shows how it is possible to evaluate temperature variations within an urban canyon, using a computational tool. It has been proved that temperature variations affects men's health. Therefore, a priori analysis can be a benefit for people as well as an aid for designers of home automation systems for internal temperature management. Furthermore, in this paper the design of a wireless sensor network (WSN) in an urban canyon is described, in order to help temperature evaluations through a fluid dynamic calculation model.

Keywords-component; Wireless Sensor Networks, Urban Canyon, CFD, Fluent.

I. INTRODUCTION

Comfort and life quality of people depend on climate conditions in their environment. Approximately 50% of world population live in urban areas. For that reason, it is necessary to study climate characteristics in urban areas. Locally, the presence of an urban area determines changes of temperature, air humidity and wind movement. In many cases, urbanization can affect the local climate of a city more intensely and more rapidly than global warming. Geiger, in the sixties, called this phenomenon "urban heat island" [1] and demonstrated that a city often presents temperature values higher than the surrounding environment. The difference during day is particularly clear a few hours after sunset. In fact, the urban environment begins to cool with a considerable delay, compared with the surrounding rural environment. This is due to heat accumulated by buildings. In this scenario, buildings placement has an important role in urban areas. In fact, these areas are increasingly characterized by the presence of "urban canyons" that represent the basic unit with which it is usually schematized the complex urban morphology. The urban canyon is formed by the air mass between two buildings facing each other. In recent years the attention of researchers focused on effects that air pollution has on urban canyons. Results showed that this geometric structure represents a trap for pollutants, derived almost exclusively from vehicular traffic. However, several studies focused on thermal conditions evaluation within urban canyons. Climate changes have been studied inside and outside urban areas, analysing effects on human health. The science that studies interactions between atmospherics phenomenon and man is “human biometeorology” [2]. This interdisciplinary science needs several skills coming from different scientific fields. This paper shows temperature values evaluated within an urban canyon using a "Computational Fluid Dynamics” software (CFD) [3], varying relative humidity, absorbed and emitted solar radiation, wind speed and emitted and absorbed thermal flux. Furthermore, a WSN design to measure temperature in an urban canyon environment will be proposed.

II. SOME RELATED RESEARCHES AND FUTURE PERSPECTIVES

In recent years, the study of airflow and pollutant dispersion in urban areas has been done using fluid dynamics models (CFD). CFD models are useful tools for air quality prediction [4]. They allow the study of pollutant dispersion flows in urban canyons. However, until now, most of the available models must be validated before being applied to particular cases study. The calculation software most used, for thermo-fluid dynamic simulations within the urban canyons, is FLUENT [3]. Recently, Santese [5] performed CFD simulations in urban canyon with heated walls. From wind speed data, using a turbulent model, it has been found a good approximation in terms of qualitative behaviour of temperature profiles [5]. However, other researches focused on natural ventilation in urban areas [6], highlighting the fact that it is less effective in urban areas than in rural areas, especially in street canyons.

In fact, in these geometric configurations, wind speed is reduced and there is the formation of urban heat island. In most cases, wind flows and pollutants dispersion characteristics have been studied both numerically and experimentally to provide a complete overview about dispersion in urban areas. A group of researchers [7], compared calculation results obtained with data field collected during three consecutive days of experimental campaigns carried out during summer, using the "MIMO" micro scale model. Results showed that wind behaviour in urban areas is more complex (vortex trend). In addition, there were no important differences between calculated values and those really measured. The presence of some variances between calculated values and measured values on the site, has been attributed to simplifications made in the initialization model. The main aim of this paper is to validate a calculation tool that can help to prevent problems to human health. In fact, it has been demonstrated that heat stress is related to mortality [6] Heat waves can cause serious health problems, especially in sensitive population groups that include individuals with cardiovascular or respiratory problems, women and elders [8]. Moreover, temperature behaviour evaluation can be a valid support in home automation in order to adjust installations in buildings that are located within an urban canyon.

III. URBAN CANYON

Studies carried out on micro-meteorological characteristics of a highly urbanized environment have shown that in the central parts of urban agglomerations, urban canyons are present. They represent the basic unit with which the complex urban morphology is organized. The urban canyon is formed by a air portion confined between two rows of very tall buildings, almost completely decoupled from the air above it, in which one or two vortices are formed, sometimes permanent and intermittent, which exchange air with the overlying atmosphere. A typical geometric configuration of a canyon is shown in Figure 1.

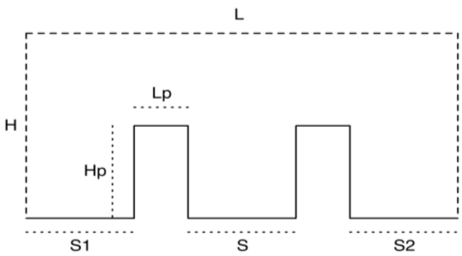

Fig. 1. Geometric configuration

Parameters and their values are described below:

- **H** represents the height of the used domain and it is equal to 60 meters;
- **L** represents the length of the used domain and it is equal to 140 meters;
- **S1** represents the length of the road before the first building and it is equal 40 meters;
- **S2** represents the length of the road before the second building and it is equal 40 meters;
- **S** represents the length of the street canyon and it is equal to 40 meters;
- **Hp** represents the height of buildings forming the street canyon and it is equal to 20 meters;
- **Lp** represents the width of buildings forming the street canyon and it is equal to 10 meters.

As shown in Figure 2, for thermal analysis of the canyon we have fixed temperature values in the calculation domain.

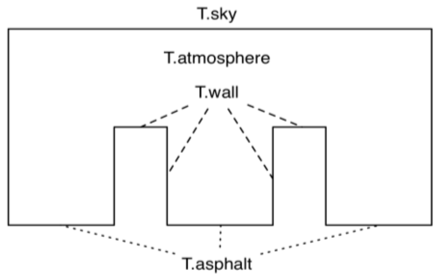

Fig. 2. Temperatures

In particular:

- **T.sky** represents the sky temperature;
- **T.atmosphere** represents the atmosphere temperature;
- **T.wall** represents building's walls temperature;
- **T.asphalt** represents asphalt temperature.

In this case, they assume values shown in Table 1.

Table 1

Sky and atmosphere temperatures

	Day-time	Night-time
T.sky	27°C	0°C
T.atmosphere	32°C	24°C

Instead, temperature of asphalt and buildings walls have been evaluated using the Air-Sun Temperature formula, varying solar radiation (*I*):

$$\mathbf{T_{A-S}} = T_a + \frac{\alpha I}{h}$$

In particular: T_a – air temperature; α – walls absorption coefficient, set equal to 0,7; h – external adduction coefficient, set equal to 20 W/m^2 °C

Wind intensity, given by an imposed parabolic profile, has been calculated as:

$$I_v = 50\frac{Log\left(\frac{y}{0.8}\right)}{Log\left(\frac{10}{0.8}\right)},$$

where y is the height of the desired domain.

Table 2

Boundary Conditions

Air Property	
Incompressible perfect fluid	
Constant density: 1,2 kg/m^3	
Constant specific heat: 1005 J/kg K	
Constant thermal conductivity: 0,0242 W/m K	
Constant viscosity: 1,79 e-05	
Asphalt Material: Dolomite	
Constant density: 2872 kg/m^3	
Constant specific heat: 910 J/kg K	
Constant thermal conductivity: 1,75 W/m K	
Constant thickness: 0,3 m	
Constant roughness: 0,3 µm	
Building's Walls Material: Poroton	
Constant density: 142 kg/m^2	
Constant specific heat: 0.840 J/kg K	
Constant thermal resistance: 214 m^2 K/W	
Constant thickness: 0,3 m	
Constant roughness: 0,3 µm	
Building's Walls Material: Insulating Layer	
Constant density: 0,7 kg/m^2	
Constant specific heat: 1,670 J/kg K	
Constant thermal resistance: 3,28 m^2 K/W	
Constant thickness: 5 cm	
Gravity acceleration	9,81 m/s^2
Initial wind speed	0,5 m/s

Considering the urban canyon, figure 3 and 4 show temperature and wind speed variation, fixing solar radiation equal to 300 W/m^2 and the thermal flux emitted from walls and asphalt during night equal to 100 W/m^2.

Figure 3 shows that there are higher temperatures, up to 308 K, in the section next to the asphalt (section1-canyon). In subsequent sections, that move away from the first one, temperatures tend to decrease, until reaching the air temperature (303 K). Furthermore, it is clear that the highest temperatures are measured near buildings walls, where there is more heat. Instead, Figure 4 shows an increase in temperature than the air temperature (300 K) inside the urban canyon. This is due to heat air flows, accumulated during the day, that the asphalt and walls of the two buildings emit during the night.

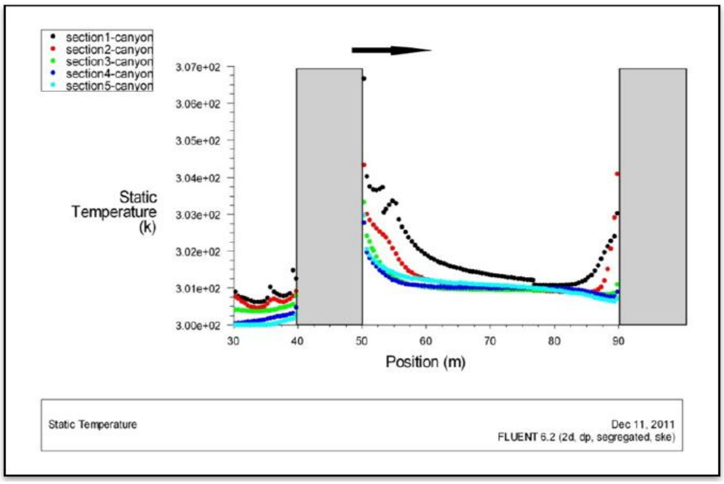

Fig. 3. Temperature changes during daytime in the urban canyon

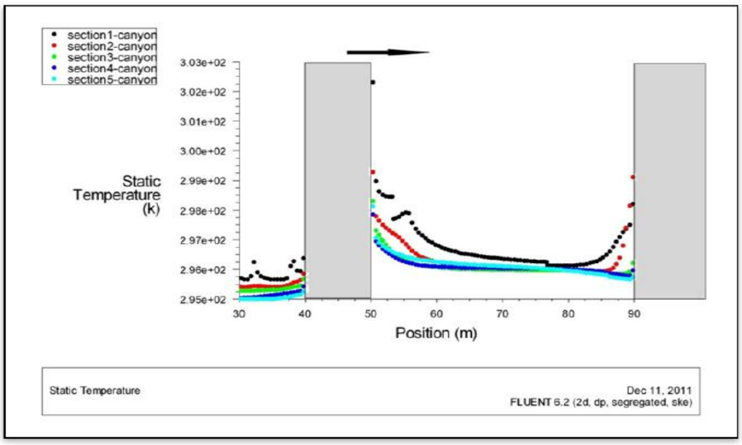

Fig. 4. Temperature changes during night-time in the urban canyon

IV. WSN DESIGN

The most common applications of WSNs in urban scenarios are fire and flooding prevention, environmental monitoring, precision agriculture, traffic monitoring and inter-vehicle sensing. The monitoring application described in this paper is represented in Figure 5 where sensor nodes must be equipped with temperature sensors to gather information about the environment temperature.

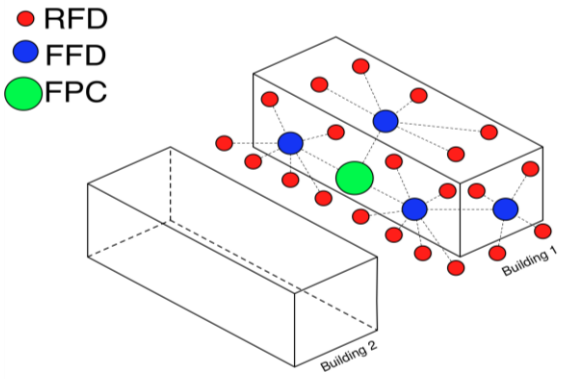

Fig. 5. WSN Architecture

To establish the wireless communication technology, it is necessary to consider the radio waves propagation in urban canyon. In [9] the simulation of radio propagation of irregular building using 3D ray tracing approach is presented. References [10] and [11] show an efficient electromagnetic-based wave propagation model in the urban canyon and urban indoor environment. Considering the relatively short distance among nodes and the possibility of a multi-hop transmission, the communication technology can be based on ZigBee wireless protocol [12], which is designed for low-power and short-range wireless communication. In Figure 5, temperature sensors (RFD nodes – Reduced Function Device) measure the environment temperature and send acquired data to their Full Function Device (FFD) nodes. An FFD node could be a ZigBee router that forward data received from RFD nodes to the Gateway (FPC node – First Pan Coordinator), which processes information. The network proposed is auto-organizing and uses a multi-hop, hierarchical and reactive routing protocol. In this way, it is easy to deploy the network without requiring any prior knowledge of the exact nodes displacement on the field. In fact, devices are able to self-configure and find the shortest path to reach the gateway. Resulting topology is a tree and the gateway, which collects data from all sensors, is the root of this network.

V. CONCLUSIONS

In this paper, parameters that determine the variation of temperature within an urban canyon have been analysed. In order to show temperature behaviour, two cases have been presented, day and night, in which different factors contribute to determine a substantial change in temperature. Finally, a Wireless Sensor Network architecture, as a valuable tool to validate FLUENT calculation model, has been shown. Both the mathematical model and the use of wireless sensor networks can be used for the design of home automation systems to regulate temperatures in indoor environments.

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