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Fuzzy Inference About Wind Resources in Urban Environment

Inferência Fuzzy para Identificar recursos eólicos em ambiente urbano

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Abstract

Technological advances allow the use of small wind towers within urban areas. It is difficult to choose the best place to set up such facilities because wind regime in micro regions suffers many influences of the surrounding environment. A wind tower may be installed and will not work properly. A fuzzy inference system dealing with this issue needs to pick up the factors that most impact the wind regime in micro urban environment. Also it uses data from the wind regime of a larger region surrounding the site. The system outputs an adequacy rank for sitting the wind tower.

Keywords: Wind energy. Artificial intelligence. Renewables.

Resumo

Os avanços tecnológicos permitem o uso de pequenas torres eólicas em áreas urbanas. É difícil escolher o melhor local para montar esse tipo de estrutura porque o regime de vento em microrregiões sofrem muitas influências do entorno ambiental. Uma torre eólica pode ser instalada e não funcionar de forma adequada. Um sistema de inferência difusa que lida com essa questão precisa captar os fatores que causam maior impacto no regime de ventos no microambiente urbano. O sistema também usa dados do regime de ventos de uma região mais ampla em torno do local. O sistema produz uma classificação para localização da torre.

Palavras-chave: Energia eólica. Inteligência artificial. Recursos renováveis.

1 Introduction

Wind energy extraction possibilities within cities are a challenging but promising research issue. It features opposite scenery to large wind farms. In the last quoted, the required great investment and the power extracted from the plant justify long-term measurement seasons, usually two or three years. As mentioned by Lange et al. (2006), in the urban environment with the prevalence of stand-alone, small turbines and custom installations for few users, a rather different

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approach is required. Shorter measurement sessions and faster investing / equipment installation decisions are necessary, notwithstanding being essential to take into account several.

Among these factors one can quote not only an obvious macroclimatic characterization of the wind regime but also a series of uncertain, fuzzy parameters hard to define accurately in an analytical way. Considering a single building where a wind turbine is supposed to be set up, the area surrounding it has many influencing factors according to Caldas (2010): nearby buildings concentration or scattering, height and shape variation of the constructions, changing of wind directions, displacement heights etc.

Taking into account the importance of knowing wind potential for urban planners, turbine manufactures, as well as for potential consumers, this research investigates a possible simpler approach for in-site wind resource estimation. It resembles the 'measure-correlate-predict' approach described by Landberg et al. (2003) but expects to replace the statistical correlation tools by a fuzzy inference one.

When traditional logical concepts are not able to assess adequately the desired parameters, fuzzy logic allows the use of vague concepts, expressing qualitative information form. To address these questions in the environment of uncertainties inherent in the mathematical models, the use of fuzzy logic proposed by Loft Zadeh in 1965 (ZADEH, 1965) fits well. It may be used to generate answers to several questions considering imprecise and contradictory data.

A recent study in the United Kingdom (MILLWARD-HOPKINS, 2013) has determined some parameters that influence the wind regime in the environment of large cities. This was done through the use of a complex data modeling with detailed geometric description of buildings and vegetation. Calculations of aerodynamic characteristics of wind regimes were performed and integrated to LIDAR (light detection and ranging) system that allowed describing and predicting the wind efficiency of the studied sites. In another research concerning urban sites, Caldas (2010) used the WindPro and WaSP software for modeling the wind regime. In this study it was noticed the need of using input data such as terrain models, roughness and buildings characteristics, which may be fuzzyficated for possible use in fuzzy systems. In the results of Millward-Hopkins studies (2013), it was suggested that the possible locations of wind turbines within a city can differ greatly concerning suitability:

> The results suggest that there are viable sites distributed thought the city, including within the complex city centre, where at the most suitable locations above-roof Wind speeds may be comparable to those observed at well exposed rural sites. However, in residential areas, consisting of groups of buildings of similar Heights, it is likely that the majority of properties will be unsuitable turbine locations. (MILLWARD-HOPKINS, 2013).

For the calibration of the fuzzy inference model using XFUZZY tool, it was necessary to create variables that could be transformed into linguistic variables, based on those that are most likely to influence the wind regime within the urban environment. The second part of this paper describes the methodology for designing the system and its outputs. Using wind data from weather station of Arraial do Cabo (Rio de Janeiro / Brazil), one may determine that according to the statistical techniques that region has an adequate potential for installing wind towers. A portable anemometer was used and measurements were taken in a short period of time at three different sites (points 1, 2 and 3 further described). These measurements were compared with those from an automatic anemometer nearby installed. It was sought to demonstrate how the variables may have some influence on the suitability for installation of wind towers and subsequent calibration of the system. In the last part of the paper the measurements are shown, as well as tables' inserts and system outputs so in the subsequent section a pre-completion of recently done studies in the region can be presented.

2 Methodology

The methodology relies on three cornerstones. At first, wind regime of a given region, obtained from large scale wind atlas is taken into account through the extraction of Weibull distribution. A simpler and faster gathering of wind regime corresponding to data acquired from an anemometer inside urban area is also considered, producing its own Weibull distribution. At a second step, the anemometer installation site, which is also a candidate location for turbine placement, is described through fuzzy sets that express the location adequacy. Finally rules relating macro and local wind distribution along with location adequacy are established for fuzzy inference purpose and processed by fuzzy inference toolkits.

2.1 Weibull Distribution from Wind Dataset

In order to describe wind potential in a given region, a well-established procedure is the use of Weibull probability distribution (DAL MONTE et al., 2012). In this work the R statistical software package 'bReeze' (GRAUL and POPPINGA, 2014) was used. Data were obtained from the automatic weather station Arraial do Cabo in the state of Rio de Janeiro, Brazil (Arraial do Cabo-A606 Code OMM: 86892 Latitude: -22.975468º Longitude: -42.021450º Height: 3 meters. Register: 23 UTC) (Figure 1). The data are based on the year 2014 from January to December. The results are shown in Figure 2 below, extracted from the data series of case study region, the resulting Weibull distribution characterizes the wind regime on the site and can directly be used for the calculation of the potential energy production of a wind turbine (GRAUL, 2015).

Figure 1 - Automatic weather station Arraial do Cabo

Source: authors (2015)

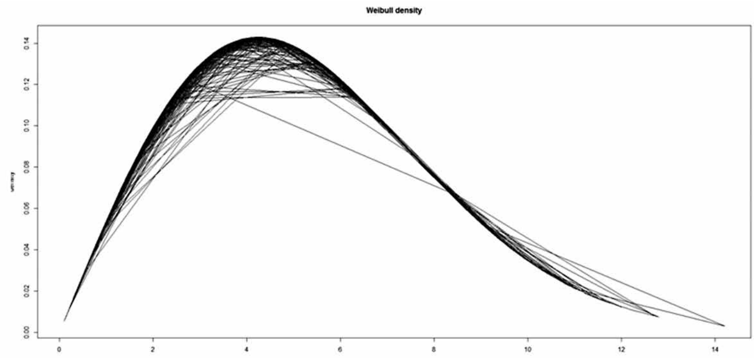

Figure 2 - Weibull density from study region dataset using bReeze package functions for wind resource assessment

Source: authors (2015)

2.2 Fuzzy Inference Rules

One of the major differences of using fuzzy inference systems is the possibility of using linguistic terms to demonstrate what one sees in reality.

> A linguistic variable u in the universe of discourse U is defined in a set of terms (or terminology), names or label, T (u), with each value being a fuzzy number set in U. For example, if u is speed, then its set of terms T (u) could be: T (speed) = {low, medium, fast} on the universe of discourse U = [0.100], where low, medium, fast, are terms or language of greatness variable speed. (SIMÕES; SHAW, 2007).

Barriga et al. (2006) show that the specification of the system can be obtained from the knowledge expressed by an expert or it can be provided by a set of numerical data, for this a possible design flow is depicted in Figure 3.

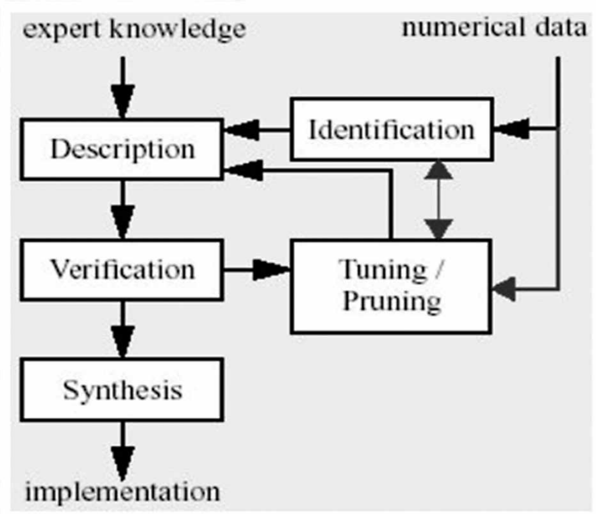

Figure 3 - Design methodology for Xfuzzy system
Source: Barriga et al., 2007

According to Barriga et al. (2006), the development environment for fuzzy system, Xfuzzy, does not impose any design methodology but it allows adapting the needs of the designer for a particular purpose. Also according to the author, the specification of the system can be obtained from the knowledge expressed by an expert or it can be provided by a set of numerical data to design the system for suitability for use vertical wind towers in urban areas was necessary to build sets of variables as follows.

Based on Beaufort scale (LISKA et al., 2013) - shown in Table 1 – was created fuzzy type *TVelocidadeVentos* (wind speed), this type of variable is necessary for use with fuzzy system in Xfuzzy:

> A linguistic variable is defined in Xfuzzy 3 by using a type object. This definition includes the name of the type, the description of the universe of discourse (its limits and discretization), the list of associated linguistic labels, and their related membership functions. Until now, membership functions had to be "free" functions selected from a package, that is, they were defined independently and could not be explicitly related among them. (BATURONE et al., 2007).

The type *TVelocidadeVentos* has its variables defined in Table 2 and its membership function is show in Figure 4.

> A family of membership functions optimization degree obtained with free functions, due to the imposed constraints. In general, free membership functions are more appropriate to describe output variables, while families of membership functions

are specially indicated to describe input variables. A good practice is to use free membership functions for variables for which no much information is available, then perform an automatic tuning or identification process to acquire some knowledge about it, and, finally, use this information to employ a suitable family if possible. (BATURONE et al., 2007).

Table 1 - Beaufort scale

Degree	Type	m/s	Ground effect
0	Calm	<0,3	Smoke rises vertically
1	Breeze	0,3 a 1,5	Smoke indicates wind direction
2	light breeze	1,6 a 3,3	The leaves move; mills start working
3	light breeze	3,4 a 5,4	Leaves flutter-and unfurl flags in the wind
4	moderate breeze	5,5 a 7,9	Dust and small raised roles; move the tree branches
5	strong breeze	8 a 10,7	Movement of large branches and small trees
6	fresh wind	10,8 a 13,8	Moving large trees; difficulty walking against the wind

Source: Liska et al., 2013

Table 2 - Fuzzy Variables based on Beaufort scale

Degree	Type	m/s	*Fuzzy variable*
0	Calm	< 0,3	mf0Calmo
1	Breeze	0,3 a 1,5	mf1Aragem
2	light breeze	1,6 a 3,3	mf2BrisaLeve
3	light breeze	3,4 a 5,4	mf3BrisaFraca
4	moderate breeze	5,5 a 7,9	mf4BrisaModerada
5	strong breeze	8 a 10,7	mf5BrisaForte
6	fresh wind	10,8 a 13,8	mf6VentoFresco

Source: authors (2015)

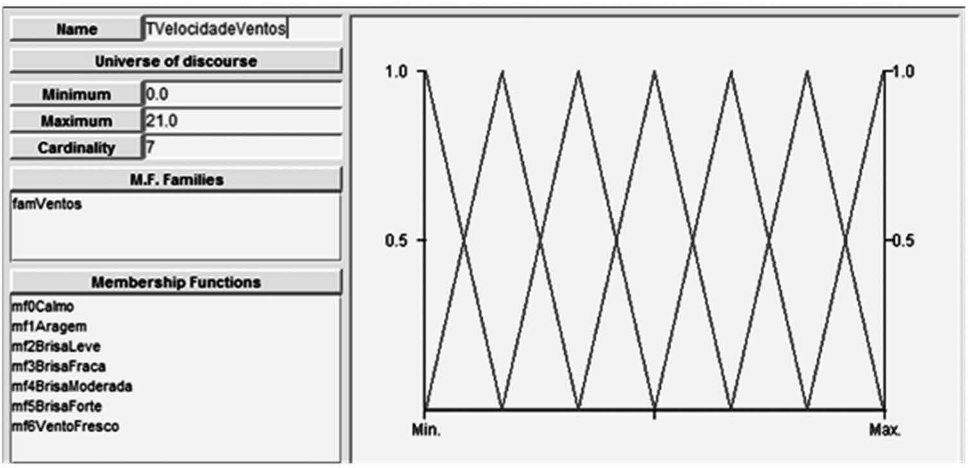

Figure 4 - A family of membership functions (BATURONE et al., 2007) for TVelocidadeVentos represented in XFUZZY based on the variables of the Beaufort scale (LISKA et al., 2013)

Source: authors, (2015)

From Troen (1989) roughness table that clusters terrain features in roughness classes (Table 3), the type Roughness' Land as *TRugosidade* was estabilished, as presented in following Table 4 and Figure 5.

Table 3 - Scale Roughness Land

z0	Terrain features	Class roughness
1,00	City	3
0,80	Forest	
0,50	outskirts	
0,40		
0,30	belts of trees	
0,20	trees and shrubs	2
0,10	farm with closed vegetation	
0,05	farm with open vegetation	
0,03	farm with few trees / buildings	1
0,02	areas of airports with buildings and trees	
0,01	areas of airport runways	
0,008	meadow	
0,005	plowed soil	
0,001	Snow	
0,0003	Sand	
0,0002		
0,0001	water (lakes, rivers, oceans)	0

Source: Caldas (2010)

Table 4 - Fuzzy variable based on roughness degrees

Class roughness	fuzzy variable
3	mf3AltaCidadeFlorestaSuburbios
2	mf2MediaAreaComArvoresArbustos
1	mf1MediaPastoAeroportosFazenda
0	mf0BaixaAreiaNeveAgua

Source: authors, (2015)

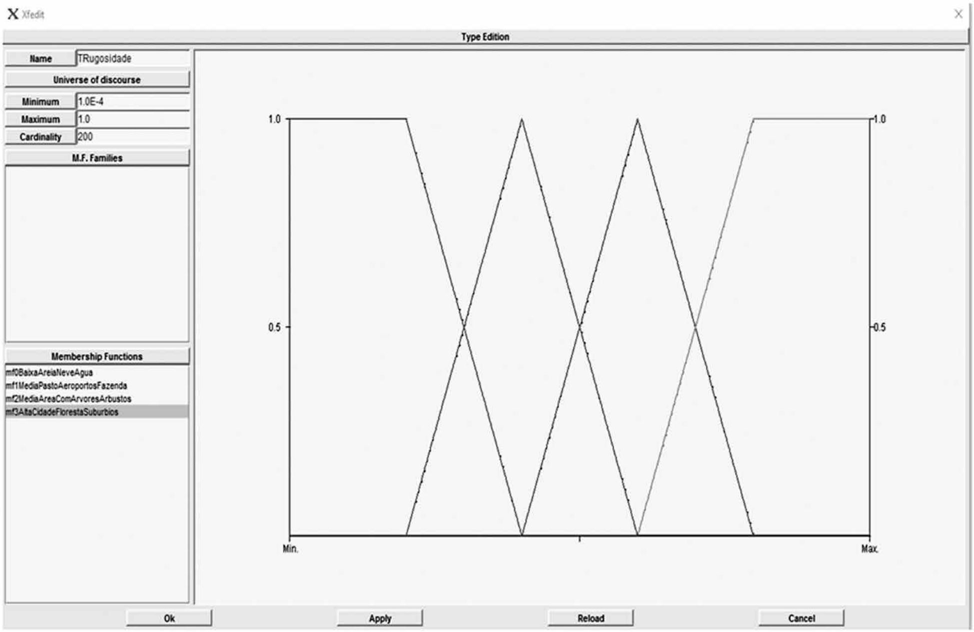

Figure 5 - membership function for type TRugosidade in XFUZZY

Source: authors, (2015)

The orography is one of the most important elements in the characterization of the atmospheric flow, according to Caldas (2010). For this *TOrografia* type was created consisting of

- mf0TerrenoPlano
- mf1ElevacoesDecliveSuave
- mf2TerrenoMontanhoso

Also were created the types:

1. *TProximidadeConstrucoes*: (proximity to buildings)
- mf0Distantes
- mf1Proximas
- mf2MuitoProximas

2. *TAlturaConstrucoes:* (height of buildings)
- mf0Baixa
- mf1Media
- mf2Altas

3. *TAlturaLocalInstalacao* : (instalation height)
- mf0Baixa
- mf1Media
- mf2Alta

4. *TAdequabilidade:* (suitability)
- mf0Baixa
- mf1Media
- mf2Alta

According to Shaw (2007), systems that use symbolic language end up requiring high computational demand, which does not occur with systems using fuzzy, as demonstrated by inference variables created. Thereby the computational analysis process becomes faster and simplified, the author talks about the nature which is indifferent to efforts to seek mathematically model their processes within which there is a certain difficulty in this, as in the case of a human operator this process becomes more streamlined. Fuzzy logic tends to behave as deductive reasoning through semantic examples that may present conclusions based on already known information, the example is the use of fuzzy controllers that can be independent and perform complex tasks without the intervention of external operators. Fuzzy logic allows data collection experts thus enabling the creation of an intelligent system to support decision based on characteristics of human intelligence.

A total of 86 inference rules were created for system tests, figure 6 demonstrates the creation of the rule bases that contain the expressions of the logical relations between the linguistic variables of the system. The XFL3 language can describe very complex relations between the variables by combining basic propositions (which compares the value of a variable with a linguistic label) via connectives and linguistic hedges (VELO et al., 2003), the Xfuzzy 3.0 provides the user a tool for software synthesis that represents the system as Java class (VELO et al., 2003) as shown in the Figure 7.

> The window for editing rule bases on xfedit presents three formats for the rule definition: matrix form, table form and free form. The matrix form constricts the rule base to two inputs and one output, and shows the rules in a compact form as a matrix. Each matrix element represents a rule like «if a is A & b is B then c is C». The table form is valid for any number of inputs and outputs, and each element of the table represents a rule like «if x0 is X0 & x1 is X1 & ... & xn is XN then z is Z». Finally, the free form allows exploiting the whole power of XFL3 to define complex relations like «if x0 is greater than X0 or not x3 is strongly equal to X3 then z is Z»" (VELO et al., 2003).

t		Rug		Orog		ProximConstr
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf1MediaPastoAeroportosFaz...	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf2MediaAreaComArvoresArb...	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf3AltaCidadeFlorestaSuburbios	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf3AltaCidadeFlorestaSuburbios	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf1ElevacoesDecliveSuave	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf2TerrenoMontanhoso	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf2TerrenoMontanhoso	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f0...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f1...	&	Rug == mf0BaixaAreiaNeveAgua	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...
f1...	&	Rug == mf1MediaPastoAeroportosFaz...	&	Orog == mf0TerrenoPlano	&	ProximConstr == m...

Figure 6 - Fuzzy Inference Rules created from XFUZZY with the window for editing rule bases on xfedit

Source: authors, (2015)

```java
public class SistemaAdequabilidadeEolica implements FuzzyInferenceEngine {

 //+++++++++++++++++++++++++++++++++++++++++++++++++++++//
 //  Rulebase RL_RegraAdequabilidade  //
 //+++++++++++++++++++++++++++++++++++++++++++++++++++++//

 private MembershipFunction[] RL_RegraAdequabilidade
 (MembershipFunction VelocVent, MembershipFunction Rug, MembershipFunction Orog,
 MembershipFunction ProximConstr, MembershipFunction AltConstr, MembershipFunction AltLocInstal) {
  double _input[] = new double[6];
  int _i_Adequabilidade=0;
  double _rl;
  _rl =
  _op.and(_op.and(_op.and(_op.and(_op.and(_t_VelocVent.mf0Calmo.isEqual(VelocVent),
  _t_Rug.mf0BaixaAreiaNeveAgua.isEqual(Rug)),_t_Orog.mf0TerrenoPlano.isEqual(Orog)),
  _t_ProximConstr.mf0Distantes.isEqual(ProximConstr)),
  _t_AltConstr.mf0Baixa.isEqual(AltConstr)),
  _t_AltLocInstal.mf0Baixa.isEqual(AltLocInstal));
  Adequabilidade.set(_i_Adequabilidade,_rl, _t_Adequabilidade.mf1NivelMedio);
  _i_Adequabilidade++;
  _rl =
  _op.and(_op.and(_op.and(_op.and(_op.and(_t_VelocVent.mf0Calmo.isEqual(VelocVent),
  _t_Rug.mf1MediaPastoAeroportosFazenda.isEqual(Rug)),
  _t_Orog.mf0TerrenoPlano.isEqual(Orog)),
  _t_ProximConstr.mf0Distantes.isEqual(ProximConstr)),
  _t_AltConstr.mf0Baixa.isEqual(AltConstr)),
```

Figure 7 - part of the Java code created from XFUZZY from rule base graphical design above using xfj module

Source: authors (2015)

2.3 Set of fuzzy logic tools

This study used a free access code tool GNU XFUZZY XML-based (MORENO VELO et al., 2012). This is JAVA programming language based tool. This kind of software allows integration with other systems, which can be useful in designing a decision support system that is available to all, as well as Juzzy is also a free also available (WAGNER et al., 2014).

3 Case Study

In order to test the proposed procedure, studies have been developed in the central eastern part of the state of Rio de Janeiro, Brazil. It was made a field investigation by consulting the wind atlas of the State of Rio de Janeiro (RIO DE JANEIRO, 2014); gathering anemometer data collection to characterize the chosen micro region (Figure 8) wind regime; and eventually site visit in 3 different points which have different nearby urban characteristics, but that are also close enough in order to proof urban environment interference concerning surrounding constructions, height of buildings, terrain and local roughness. This was done by measurement using a simple handheld anemometer, thus demonstrating how the new approach can simplify the process of investigation of the wind potential of a region with the use of a portable device, site observation and using the developed system that assumes the characterization of uncertainties by fuzzy variables.

The study was done with five measurements on July 13th, 2015, a day with few clouds and big gusts of winds. A portable anemometer with coupled and adapted tripod to not interfere with the measurements was used, being placed at a low height of approximately 1.10 m. The chose points are described as follows:

- Point 1 is approximately 50 m from the automatic weather station on the beach with no buildings around with low topography and low roughness of the terrain with good incidence of winds;
- Point 2 is 80 m from the automatic weather station and in urban areas with buildings around with a rise of 4m in relation to sea level;
- Point 3 is approximately 300 m from the automatic weather station at the foot of a hill and with plenty of buildings around, beyond the asphalt.

Figure 8 - Angels Beach Arraial do Cabo - RJ measurement location

Source: Google Earth, (2015)

Figure 9 - Point 1

Source: authors, (2015)

Figure 10 - Point 2
Source: authors, (2015)

Figure 11 - Point 3
Source: authors, (2015)

4 Results

To process the collected data it was used a fuzzy system created in XFUZZY in the Verification-Monitorization module (reference). The system design is shown in Figure 12, and results from a suitability inference test is presented in Figure 13. Gathered and fuzzyfied data from points 1, 2 and 3 are also displayed from Table 5 to 10.

> Xfuzzy 3.0 contains two tools for describing fuzzy systems: xfedit and xfpkg. The first one is dedicated to the logical definition of the system, that is, the definition of its linguistic variables and the logical relations between them. Although this description can be done by editing a file with a ".xfl" extension, the tool xfedit offers a graphical interface which avoids the need for a deep knowledge of the XFL3 language. The user defines the hierarchy of the system at the main window of xfedit. (VELO et al., 2003).

The logic of the relationship between different types of variables created to fuzzy inference system proposed for measuring the wind profiling efficiency in urban areas can be seen in Figure 12.

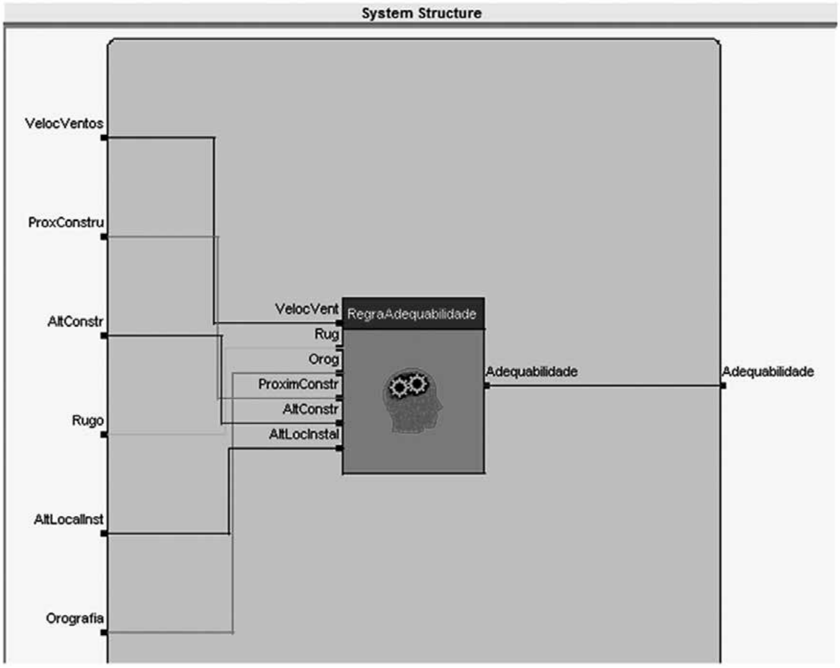

Figure 12 - Logical relationship between different types of variables fo wind profiling efficiency

Source: authors, (2015)

> The objective of the verification stage is to study the behavior of the system under development, detecting probable deviations on the expected behavior and identifying the source of these deviations. Xfuzzy 3.0 contains four verification tools for these purposes: xf2dplot, xf3dplot, xfmt, and xfsim. (VELO et al., 2003).

Even as quotes Velo (2003) the tool xfmt allows monitoring the system at all the hierarchical levels, showing the activation degree of every linguistic label and logical rule, as well as the value of the different inner variables, for some determined input values. The figure 13 shows the main window of xfmt that corresponds to the top level of the system hierarchy.

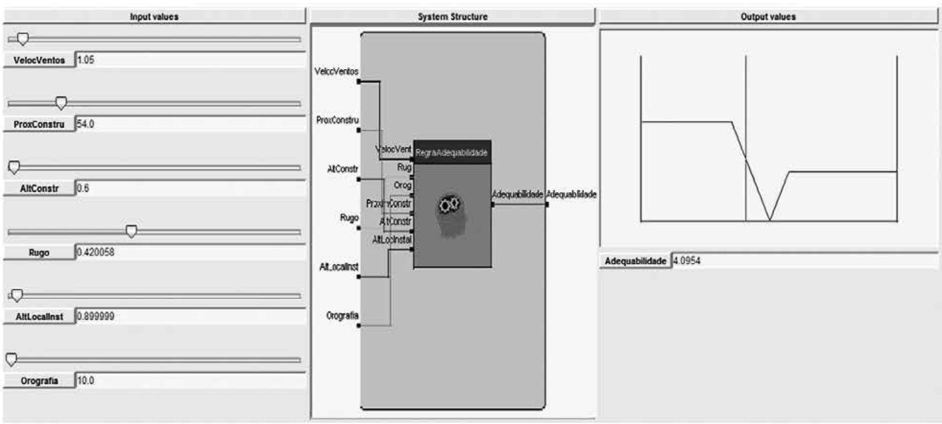

Figure 13 - Verification stage using xfmt tools from XFUZZY

Source: authors, (2015)

Recorded measurements for the selected points follows:

- Point 1:

Table 5 - Record of measured data in the site

Date	Time	Wind speed m/s	Temperature º C
11/07/2015	11h:45min	5.3	25
11/07/2015	12h:45min	5.5	25
11/07/2015	14h:00min	4.5	24
11/07/2015	15h:00min	2.8	28
11/07/2015	16h:00min	2.0	25

Source: authors, 2015

Table 6 - Profile section 1

Roughness	sand - 0,003	mf1
Average winds speed	4.02 m/s – Weak breeze 3	mf3
High buildings	low	mf0
Buildings proximity	distant	mf0
Orography	0m	mf0
Local height installation	Low 1.10m	mf0
Weather station distance	50m	
Suitability (using fuzzy)	mean	

Source: authors, 2015

- Point 2:

Table 7 - Record of measured data in the site

Date	Time	Wind speed m/s	Temperature º C
07/11/2015	11h:50min	2.2	28
07/11/2015	12h:50min	2.3	28
07/11/2015	14h:10min	2.1	28
07/11/2015	15h:10min	2.1	28
07/11/2015	16h:10min	2.0	25.9

Source: authors, 2015

Table 8 - Profile section 2

Roughness	City - 1	mf3
Average winds speed	2.14 m/s – weak breeze 2	mf2
High buildings	means	mf1
Buildings proximity	near	mf1
Orography	4m	mf1
Local height installation	Low 1.10m	mf0
Weather station distance	80m	
Suitability (using fuzzy)	High	

Source: authors, 2015

- Point 3:

Table 9 - Record of measured data in the site

Date	Time	Wind speed m/s	Temperature º C
07/11/2015	12h:00min	1.3	28.1
07/11/2015	13h:00min	2.3	28
07/11/2015	14h:20min	1.2	29
07/11/2015	15h:20min	0.9	27
07/11/2015	16h:20min	1.0	24

Source: authors, 2015

Table 10 - Profile section 3

Roughness	City - 1	mf3
Average winds speed	1.34 m/s – breeze 1	mf1
High buildings	means	mf1
Buildings proximity	Very close	mf3
Orography	6m	mf2
Local height installation	low 1.10m	mf0
Weather station distance	300m	
Suitability (using fuzzy)	low	

Source: Authors, 2015

5 Conclusion

Preliminary tests suggest the feasibility of the proposed method. Further testing is required for the verification of the method according to proposed rules of inference. This is also necessary for the calibration and set up of new inference rules. An initial observation of the urban environment, at a windy location may suggest a suitable site for installation of small wind towers. Notwithstanding, the measurements taken at the place showed that some parameters must be considered as terrain and nearby buildings. This demonstrates that the method is appropriate. In the case study that happened in point 3 installation, which is placed at the foot of a hill with lots of buildings around, it pointed out that it would not be a good place to install wind towers on top of houses.

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