FUZZY INFERENCE ABOUT WIND RESOURCES IN URBAN ENVIRONMENT

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ABSTRACT

The advancement of renewable energy technology gave rise to the implementation of small wind towers in urban areas. A major problem in predicting the use of such facilities is the difficulty of measuring in micro-regions that suffer different influences of the surrounding environment. Thus a wind tower may be installed where it does not work properly. Fuzzy inference systems try to approach the thinking process of human language allowing for a more assertive decision process. For the development of a fuzzy inference system dealing with this issue it was necessary to determine the variables that most impact on the variation of the wind distribution in micro urban environment as well as using data from automatic weather stations which allow to estimate the wind regime for a macro region. These data are fed in a fuzzy inference system that outputs an adequacy rank for sitting a small wind tower.

Keywords: wind energy, artificial intelligence, renewables

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. In the urban environment with the prevalence of stand-alone, small turbines and custom installations for users a rather different approach is required. Shorter measurement sessions and faster investing / equipment installation decisions are necessary, notwithstanding being essential to take into account several factors.

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: nearby buildings concentration or scattering, height and shape variation of the constructions, changing of wind directions, displacement heights, etc.

Considering 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 differences in the environment of the uncertainties of the common mathematical models, the use of fuzzy logic proposed by Loft Zadeh in 1965, can be used to generate answers to several questions considering imprecise and contradictory data.

In recent studies in the United Kingdom Hopkins (2013) determined some parameters that influence the wind regime in the environment of large cities. This is done through the use of a complex data modeling with detailed geometric description of buildings and vegetation. Calculations of aerodynamic characteristics of wind regimes are performed and integrated to LIDAR system (light detection and ranging) that allowed to describe and predict the wind efficiency of the studied sites. In another study Caldas (2010) uses the WindPro and WaSP software for modeling the wind regime. In that study it is noticed the need of using input data as terrain models, roughness and constructs which may be fuzzyficated for possible use in fuzzy systems. The results of Hopkins studies (2013), it is 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 residencial áreas, consisting of groups of buildings of similar Heights, it is likely that the majority of properties will be unsuitable turbine locations.”*(Hopkins, .2013).

For calibration of the fuzzy inference model using XFUZZY tool, it was necessary creating 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 article 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 region has an adequate potential for installing wind towers. By using a portable anemometer and measuring in a short period of time three different points compared with the automatic anemometer 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 third part of the article the measurements are shown, as well as tables inserts and system outputs so in the subsequent section a pre-completion of studies done recently in the region can be given.

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 Weilbull 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. Weilbul Distribution from Wind Dataset

In order to describe wind potential in a given region, a well-established procedure is the use of Weilbull probability distribution (Dal Monte et al, 2012). In this work the R 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 Station-A606 OMM = 86892 (Figure 2) based on the year 2014 from January to December. The results are shown in Figure 1 below, extracted from the data series of case study region.

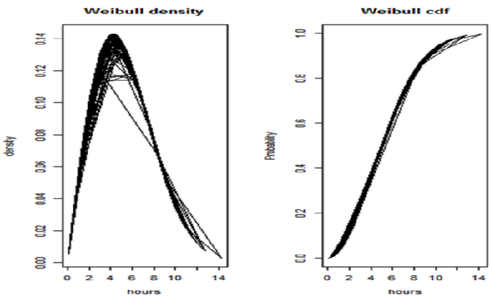


Figure 1: Weibull Distribution from study region dataset

Figure 2: Arraial do Cabo-A606 Code OMM: 86892 Latitude: -22.975468º Longitude: -42.021450º Height: 3 meters. Register: 23 UTC

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”*. (Shaw, 2007).

To design the system for suitability for use vertical wind towers in urban areas was necessary to build sets of variables which the following. Based on Beaufort scale (LISKA et al, 2013) the variable *TVelocidadeVentos* (wind speed):

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

Table 2 Fuzzy Variables based on the scale of Beaufort

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

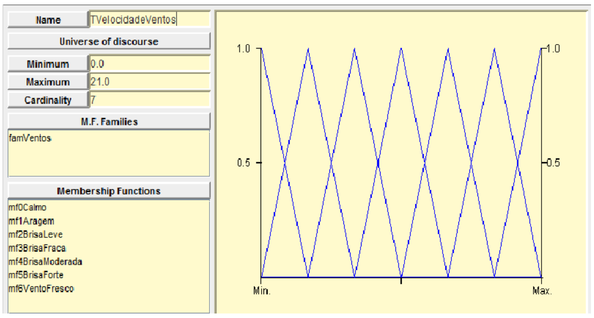

Name TVelocidadeVentos
Universe of discourse
Minimum 0.0
Maximum 21.0
Cardinality 7
M.F. Families
famVentos
Membership Functions
mf0Calmo
mf1Aragem
mf2BrisaLeve
mf3BrisaFraca
mf4BrisaModerada
mf5BrisaForte
mf6VentoFresco

Figure 1. TVelocidadeVentos in XFUZZY

Roughness Land as *TRugosidade* based on *European Wind Atlas (1989)* roughness table that clusters terrain features in roughness classes.

Table 3 Scale Roughness Land Caldas (2010)

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

Table 3 Fuzzy variable based on roughness degrees

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

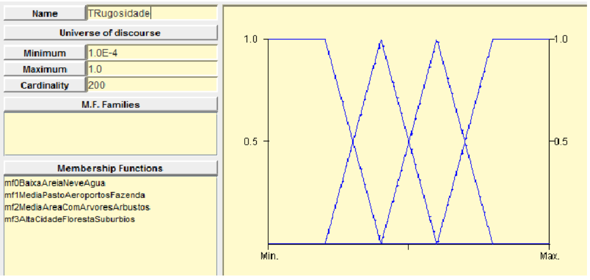

Name TRugosidade
Universe of discourse
Minimum 1.0E-4
Maximum 1.0
Cardinality 200
M.F. Families
Membership Functions
mf0BaixaAreiaNeveAgua
mf1MediaPastoAeroportosFazenda
mf2MediaAreaComArvoresArbustos
mf3AltaCidadeFlorestaSuburbios

Figure 4 variable TRugosidade in XFUZZY

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 variables:

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

- *mf2MuitoProximas*

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

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

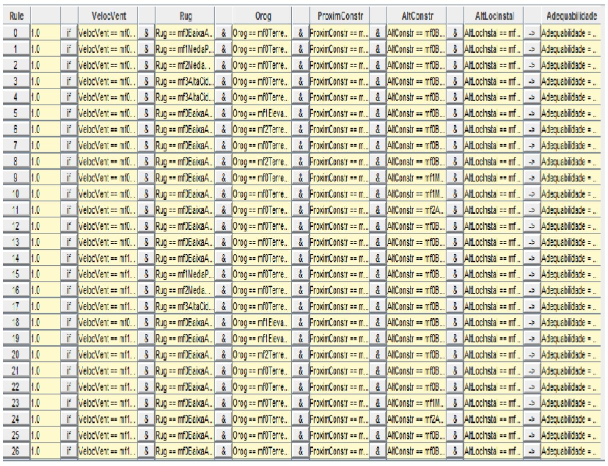
4. *TAdequabilidade:* (suitability)
    - mf0Baixa
    - mf1Media
    - mf2Alta

Based on input variables the rules of fuzzy inference were created which do not require high computational demand as systems using symbolic computation (Shaw, 2007).

Expert systems that use progressive inference, also called "forward-chained inference" generally employ discrete variables or symbolic variables converted into discrete numbers. As a result, end up dealing with a huge number of rules, hundreds and often thousands are used in the knowledge base. This order of magnitude is much greater than the number of rules typically used in a fuzzy system (typically between 20 and 100).

In addition, the expert system rules are triggered in series, not in parallel. Its true purpose is to conduct some kind of diagnosis, acting as a director or giving suggestions (Shaw, 2007).

A total of 86 inference rules were created for system tests, as shown in Figures 5 and 6.



Rule			VelocVent		Rug		Orog		ProximConstr		AltConstr		AltLocInstal		Adequabilidade
0	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
1	1.0	if	VelocVent == mf0...	&	Rug == mf1MediaP...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
2	1.0	if	VelocVent == mf0...	&	Rug == mf2Media...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
3	1.0	if	VelocVent == mf0...	&	Rug == mf3AltaCid...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
4	1.0	if	VelocVent == mf0...	&	Rug == mf3AltaCid...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
5	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf1Eleva...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
6	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf2Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
7	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
8	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf2Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
9	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf1M...	&	AltLocInsta == mf...	->	Adequabilidade = ...
10	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf1M...	&	AltLocInsta == mf...	->	Adequabilidade = ...
11	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf2A...	&	AltLocInsta == mf...	->	Adequabilidade = ...
12	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
13	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
14	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
15	1.0	if	VelocVent == mf1...	&	Rug == mf1MediaP...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
16	1.0	if	VelocVent == mf1...	&	Rug == mf2Media...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
17	1.0	if	VelocVent == mf1...	&	Rug == mf3AltaCid...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
18	1.0	if	VelocVent == mf0...	&	Rug == mf0BaixaA...	&	Orog == mf1Eleva...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
19	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf1Eleva...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
20	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf2Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
21	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
22	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
23	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf1M...	&	AltLocInsta == mf...	->	Adequabilidade = ...
24	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf2A...	&	AltLocInsta == mf...	->	Adequabilidade = ...
25	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...
26	1.0	if	VelocVent == mf1...	&	Rug == mf0BaixaA...	&	Orog == mf0Terre...	&	ProximConstr == m...	&	AltConstr == mf0B...	&	AltLocInsta == mf...	->	Adequabilidade = ...

Figure 5 Fuzzy Inference Rules created from XFUZZY

```
rulebase RegraAdequabilidade (TVelocidadeVentos VelocVent, TRugosidade Rug, TOrografia Orog, TProximidadeConstrucoes ProximConstr, TAlturaConstrucoes AltConstr, TAlturaLocalInstalacao A
  if(VelocVent == mf0Calmo & Rug == mf0BaixaAreiaNeveAgua & Orog == mf0TerrenoPlano & ProximConstr == mf0Distantes & AltConstr == mf0Baixa & AltLocInstal == mf0Baixa)
  -> Adequabilidade = mf1NivelMedio;
  if(VelocVent == mf0Calmo & Rug == mf1MediaPastoAeroportosFazenda & Orog == mf0TerrenoPlano & ProximConstr == mf0Distantes & AltConstr == mf0Baixa & AltLocInstal == mf0Baixa
  -> Adequabilidade = mf0NivelBaixo;
  if(VelocVent == mf0Calmo & Rug == mf2MediaAreaComArvoresArbustos & Orog == mf0TerrenoPlano & ProximConstr == mf0Distantes & AltConstr == mf0Baixa & AltLocInstal == mf0Baixa
  -> Adequabilidade = mf0NivelBaixo;
  if(VelocVent == mf0Calmo & Rug == mf3AltaCidadeFlorestaSuburbios & Orog == mf0TerrenoPlano & ProximConstr == mf0Distantes & AltConstr == mf0Baixa & AltLocInstal == mf0Baixa
  -> Adequabilidade = mf0NivelBaixo;
  if(VelocVent == mf0Calmo & Rug == mf3AltaCidadeFlorestaSuburbios & Orog == mf0TerrenoPlano & ProximConstr == mf0Distantes & AltConstr == mf0Baixa & AltLocInstal == mf0Baixa
  -> Adequabilidade = mf0NivelBaixo;
```

Figure 6 Code Created from XFUZZY

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).

2.4 Case Study

In order to test the developed procedure, studies have been developed in the central eastern part of the state of Rio de Janeiro, Brazil. It was made an investigation of the site by observing the wind atlas of the State of Rio de Janeiro, anemometer data collection to profile the wind regime of the region and site visit in 3 different points with different characteristics, but nearby enough to proof of urban interference with respect to surrounding constructions, height of buildings, terrain and local roughness measurement using a simple handheld anemometer, assuming the simplicity of logic characterized by uncertainties.

The study was done with 5 measurements on July 13, 2015, 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.

- Point 1 is approximately 50m 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 80m 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 300m from the automatic weather station at the foot of a hill and with plenty of buildings around, beyond the asphalt.

Figure 7 Angels Beach Arraial do Cabo - RJ measurement location, source: Google Earth

Figure 8 point 1 source: author

Figure 9 Point 2 source: author

Figure 10 Point 3 Source: author

3. RESULTS

To process the collected data it was used a fuzzy system created in XFUZZY in the Verification-Monitorization module.

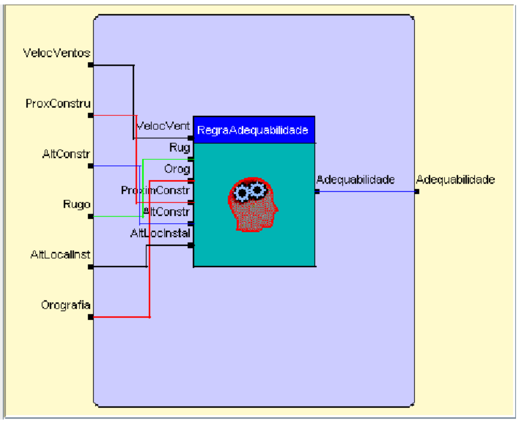
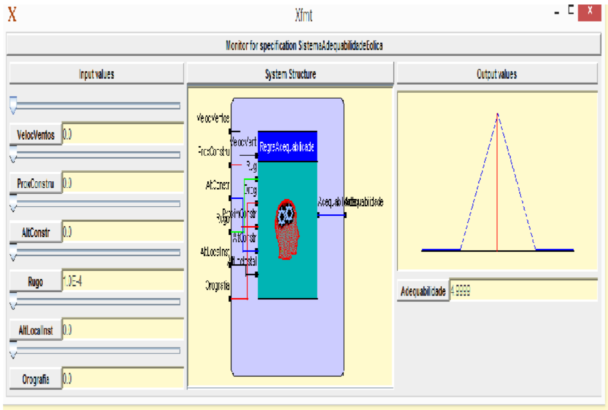


Figure 11 System Suitability Fuzzy created with the tool XFUZZY



Monitor for specification SistemaAdequabilidadeEolica

VelocVentos 0.0
ProxConstru 0.0
AltConstr 0.0
Rugo 1.0E-4
AltLocalInst 0.0
Orografia 0.0
Adequabilidade 4.9999

Figure 12 Monitoring with XFUZZY

Recorded measurements for the selected points:

- Point 1:

Table 5. Record of measured data in the site. source: author

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

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	

- Point 2:

Table 7 Record of measured data in the site source: author

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

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	

- Point 3:

Table 9 Record of measured data in the site. source: author

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

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	

4. CONCLUSION

Preliminary tests suggest the feasibility of the proposed method. Further testing is required for verification of the method according to the proposed rules of inference. An initial observation the urban environment, in a place with lots of winds may seem suitable for installation of small wind towers, but some parameters must be considered as terrain and nearby buildings, as demonstrated in the case study where the installation in site 3 which is at the foot of a hill with lots of buildings around demonstrates not being a good place to install wind towers on top of houses.

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