The Effects of Climate Change in Rainfall Drainage Systems Design

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1. Introduction

Global warming and climate change are two topics that have been studied deeply in the last few decades. Scientific research has proved that climate change affected and will continue to affect the planet Earth. In 1998, the Intergovernmental Panel on Climate Change (IPCC) was created with the sole purpose of gathering information about global warming and climate change. Since that, the IPCC have published several reports with the results of their studies.

The fifth, and last report, IPCC Fifth Assessment Report (IPCC, 2014), refers that the most recent values of anthropogenic emissions of greenhouse gases are the highest in history. Consequently, the atmosphere's and oceans' temperature has increased, as well as the quantity of snow and ice has decreased, thus raising the sea´s level. The IPCC also identified some changes in extreme weather events, such as a decrease of the lowest temperatures and an increase of the highest temperatures and of the number of heavy rainfall events.

Other authors, such as Croitoru, Piticar, & Burada (2016) e Wang, Jiang, & Lang (2017), also came to the conclusion that there is a tendency to observe a larger number extreme precipitation events.

Rainwater drainage systems are designed considering the intensity of rain and its probability of occurrence. In Portugal, the design of such systems is done according current legislation *(Law -Decree 23/95).*

The goal of the resent work is to determinate whether climate changes influence building design of rainwater drainage systems. To achieve such goal, it is necessary to determinate new intensity-duration-frequency (IDF) curves considering current data of precipitation.

2. Literature Review

Most studies on IDF curves in Portugal were carried out in the late XXth century. The most important studies are the following:

- Godinho (1984, 1989 and 1991) published a study on maximum annual values of precipitation for durations lower than one hour.

- Matos e Silva (1986) published a study where a methodology to obtain IDF curves was given. The IDF curves given in the form $I=at^b$, where a and b are parameters given in the Table 1 as a function of the return period and of the location (the country was divided in 3 regions A, B and C).

Table 1 - IDF parameters according to the region and return period (extracted from Matos and Silva 1986)

Regions	A		B		C	
T (years)	a	b	a	b	a	b
2	202,72	-0,577	162,18	-0,577	243,26	-0,577
5	259,26	-0,562	207,41	-0,562	311,11	-0,562
10	290,68	-0,549	232,21	-0,549	348,82	-0,549
20	317,74	-0,538	254,19	-0,538	381,29	-0,538
50	349,54	-0,524	279,63	-0,524	419,45	-0,524
100	365,62	-0,508	292,50	-0,508	438,75	-0,508

- Pereira (1995) presented a methodology that allows the use of informatic software to obtain IDF curves in a reliable way.
- Pereira e Rodrigues (1998) published IDF curves for 17 udographics stations and Pereira, Rodrigues e Costa (2001) determined 27 new curves IDF using the methodology proposed by Pereira (1995).

3. Methodology

In order to determine the parameters of the intensity-duration-frequency curves, it is necessary to create a database with the values of precipitation. To accomplish that, 5 udographic stations with enough data describing the 60-year period of analysis, between the hydrological years of 1958 and 2017, were chosen. A hydrological year, in Portugal, goes from the first day of October (1/10) to the last of September (30/9) next year. Table 2 shows the main characteristics of these 5 udographic stations.

Table 2 - Characteristics of the rainfall stations

Name (location)	Reference	District	X (m)	Y (m)	Altitude(m)
Barragem de Magos	20E/01C	Santarém	151370	224830	43
Covilhã	12L/03G	Castelo Branco	252965.162	368653.291	719
Monchique	30F/01C	Faro	159096	39736	792
São Julião do Tojal	20C/01C	Lisboa	114090	208796	6
Vila da Ponte	03J/05G	Vila Real	219743.843	527520.873	745

All the information data used in the present work was obtained with the help of the department of monitorization of hydric resources, from the Portuguese environment agency (APA).

The next stage after collecting data, was to identify and fill in missing precipitation values. After that, it was determined the maximum annual value of precipitation for 8 different series considering durations of 5 10, 15 and 30 minutes and 1, 2, 6 and 12 hours. Then a statistical study was carried out and the values of the mean, standard deviation, asymmetry coefficient and kurtosis coefficient were determined (Naghettini, M. & Pinto, 2007).

The series were then adjusted according to the Gumbel's distribution function:

$$F(x) = e^{-e^{(-\frac{x-\beta}{\alpha})}} \qquad \text{for } -\infty < x < +\infty,\ -\infty < \beta < +\infty\ , \qquad (1)$$

where α e β are the distribution parameters expressed as:

$$\alpha = \frac{\sqrt{6}s}{\pi}\ , \qquad \text{where } s > 0\ ; \qquad (2)$$

$$\beta = \bar{x} - 0.5772\alpha\ , \qquad \text{for } -\infty < \bar{x} < +\infty\ . \qquad (3)$$

The quantile of precipitation was than estimated considering 7 different return periods: 2, 5, 10, 50, 100, 500 and 1000 years. These quantiles were determined using the Gumbel's distribution, where the variable was the precipitation, according to:

$$x = \beta - \alpha.Ln\{-Ln[F(x)]\}, \qquad (4)$$

Finally, using the quantiles determined above, one can obtain the paraments a and b required by IDF exponential curves:

$$i = at^b\ , \qquad (5)$$

where t represents the duration of precipitation, in minutes. A logarithmic operator was used to obtain a linearized equation and then determine parameters a and b, by linear regression:

$$\ln i = \ln a + b.ln\ t, \qquad (6)$$

Since one of the objectives of this dissertation is to compare the values of the new curves IDF with the ones used in existing regulation (DR23/95), these curves were calculated for the 3 regions as defined by Matos and Silva (1986). In order to determinate the parameters for region A, the quantiles of precipitation of all the 5 stations udographics were used. The Table 3 shows the value of parameters *a* and *b* for regions A, B and C for different return periods.

Table 3 - Estimated parameters of IDF curves according to the region

T (years)	A		B		C	
	a	b	a	b	a	b
2	203,894	-0,596	163,115	-0,596	244,673	-0,596
5	323,339	-0,618	258,671	-0,618	388,006	-0,618
10	402,945	-0,626	322,356	-0,626	483,534	-0,626
50	578,767	-0,638	463,014	-0,638	694,520	-0,638
100	653,276	-0,641	522,621	-0,641	783,931	-0,641
500	825,509	-0,646	660,407	-0,646	990,611	-0,646
1000	899,645	-0,647	719,716	-0,647	1079,574	-0,647

4. Precipitations tendencies

In order to identify precipitation tendencies, it was decided to study the data collected in series of 30 consecutive years. For better understanding of the variation of the precipitation, linear tendency curves were added to the plot.

The analysis of the stations of Barragem de Magos, Covilhã, São Julião do Tojal and Vila da Ponte has showed that there is a positive tendency in the series of lower duration (5, 10 and 15 minutes) opposing the negative tendency of the higher duration series (2, 6 and 12 hours). This means that the intensity of precipitation is nowadays higher in short durations and lower in longer durations, when compared to 30 to 60 years ago.

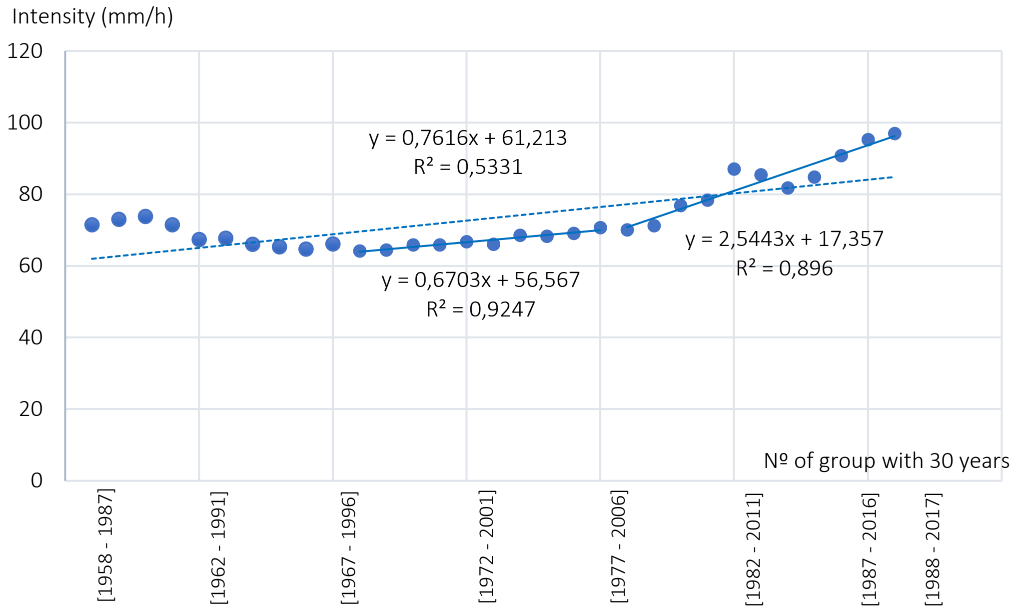

Figure 1 – Variation of the estimated precipitation over the last 60 years in São Julião do Tojal, considering 5 minutes of precipitation and a return period of 2 years.

In Figure 1, referring to series of 30 years and 5 minutes of durations of the station de São Julião do Tojal, for a return period of 2 years, a clear positive tendency of the variation of intensity of precipitation is observed from the first group (1958 to 1987) to the last group (1989-2018). Analysing closely the last 40 years and increase in the slope is evident. These results prove an increase of the precipitation intensity, particularly after the 80's of the XXth century.

When the series of 30 minutes is analysed, it's verified that although the tendency is still positive, the slope is lower than that of the series of 5 minutes. However, an acceleration of the intensity increase is still visible since the 1980's decade. The series of higher duration, as for example, the series of 6 hours precipitation, shows a negative tendency which implies a decrease in the intensity.

As rated before, one of the consequences of climate change is the change of the precipitation's pattern. Based on the analysis of the different graphics created, it's clear that there is an increase of the sort precipitation intensity and a decrease of the intensity of long precipitation series.

5. Case study

In order to assess, in a preliminary approach, whether climate affects designing of building rainwater drainage systems, a case of study will be considered, manually, a 8-story residential building located at

Praça de Espanha, Lisbon. The building also has 3 layers of roofs alongside with balconies and includes 3 basements for car parking and other uses.

A residential building must have 2 separated drainage systems, one for wastewater and another one for rainwater. In this case of study, it was decided that all the visible pipes would be in cast iron, the gutters moulded in mortar, and buried pipes in PVC. The design of the drainage system complies with the Portuguese regulations (DR23/95) in all aspects.

In this case study, 2 different drainage systems were considered for raised and buried floors. The first includes moulded gutters, downpipe and sewers. The system of the basements has, in addition, inspection chambers and a hydraulic pump.

5.1. Rainwater drainage system above ground

In order to asset the effects of using new IDF curves,12 different scenarios were considered. In all of them, the duration of precipitation is 5 minutes, occurring in the region A, B and C for a return period of 5 and 10 years. Table 4 it's shows the different scenarios and the corresponding parameters.

Table 4 - Different scenarios and IDF parameters a and b

Scenarios	IDF curves	Return period (years)	Region	a	b	Intensity	
						(mm/h)	l(min.m²)
1	LD23/95	5	A	259,26	-0,562	104,93	1,75
2	LD23/95	10	A	290,68	-0,549	120,14	2,00
3	LD23/95	5	B	207,41	-0,562	83,95	1,40
4	LD23/95	10	B	232,24	-0,549	95,98	1,60
5	LD23/95	5	C	311,11	-0,562	125,92	2,10
6	LD23/95	10	C	348,82	-0,549	144,17	2,40
7	New Curves	5	A	323,339	-0,618	119,59	1,99
8	New Curves	10	A	402,945	-0,626	147,13	2,45
9	New Curves	5	B	258,671	-0,618	95,67	1,59
10	New Curves	10	B	322,356	-0,626	117,70	1,96
11	New Curves	5	C	388,006	-0,618	143,51	2,39
12	New Curves	10	C	483,534	-0,626	176,55	2,94

For a better comparison between the different scenarios, only the diameters of each components (pipes) will vary, maintaining the slope constant.

5.2. Underground water drainage system

The design of the rainwater drainage system in the basements is independent of the rainfall intensity, therefore there is no need to design for the 12 scenarios. This system will drain the water which infiltrated through walls and also of firefighting systems, in this case, 2 fire hydrant systems and an automatic sprinkler system. The discharge of the firefighting system is 980 L/s.m^3, so the drainage system needs to be designed for this flow.

5.3. Budget Analysis

One of the main objectives of this dissertation is to assess the impact of climate change on the design of building rainfall drainage systems and, for that reason, a budget analysis was carried out. In this analysis, only material costs were considered, assuming as fixed the cost of transportation, installation and work labour.

The first step of this analysis is to estimate the costs of each material and the costs of specialized and non-specialized labour and those of installation.

A profit margin of 25% was considered on assessing total costs (Ct) which are those given by:

$$Ct = 1{,}25 * (Cm + Ci), \quad (7)$$

where Cm (€/m) are the material and Ci (€/m) installation costs.

The total costs used in this budget analysis are as follow in the Table 5.

Table 5 - Total cost of each component of the rainwater drainage system

Total Costs (€/m)			
DN (mm)	Gutters	Visible drainpipes (Cast Iron)	Buried drainpipes (PVC)
25	9,08		
50	9,26	27,16	
75	9,39	30,15	
100	9,46	34,95	
110			16,02
125	9,49	44,70	16,79
150		54,43	19,19
200		84,73	23,84
250			31,54

Considering the total network, the total costs of the rainwater drainage system for the 1st and 7th scenarios is, respectively and illustrative, 30.878,93€ and 31.060,15€.

6. Results

In this section, the results obtained in the different scenarios considered are analysed. As shown in Table, which contains the parameters and the rainfall intensity for each scenario, there is an increase of rainfall intensity with the new IDF curves compared with the ones given in current legislation (LR23/95) for the same return period and precipitation duration. These results reflect an increase of rainfall intensity for short-duration precipitation in each of the 3 regions.

The results also showed that the intensity values obtained with the new IDF curves for a return period of 5 years are very similar those obtained with the IDF curves of the regulation (LR23/95) for a return period of 10 years (Table 6).

Based on the data collected, one finds out that the precipitation events that once were supposed to occur every 10 years, now occur every 5 years.

Table 6- Comparison of the IDF parameters for different return periods

IDF Curves	Return period (years)	Region	Intensity	
			(mm/h)	l(min.m2)
Regulation (LR23/95)	10	A	120,14	2,00
New (Chap. 4)	5	A	119,59	1,99
Regulation (LR23/95)	10	B	95,98	1,60
New (Chap. 4)	5	B	95,67	1,59
Regulation (LR23/95)	10	C	144,17	2,40
New	5	C	143,51	2,39

6.1. Design

The rainwater drainage system design is based on the precipitation intensity values, therefore, since these values increase with new IDF curves, it is expected to obtain an increase in the diameters of some components of these systems.

After the comparison of the new IDF curves with those given in current legislation, changes were identified in the 3 regions. In region A, 6 components increased the diameter (4 gutters, 1 downpipe and 1 sewer). In region B, also 6 components changed diameters, but most of them are sewers (2 gutters, 1 downpipe and 3 sewers). In region C, only 5 components increased diameters (1 gutter, 2 downpipes and 2 sewer).

This comparison shows that climate change has, in fact, an impact in building rainwater drainage systems. Although impact is not visible in the entire system, the current legislation is insufficient provide the required drainage capacity. A drainage system that fails to drain the water could cause infiltration in apartments or common areas, thus damaging the building. A revision of the legislation could prevent such failures, or at least minimize the probability of these sort of shortfalls.

6.2. Budget analysis

Since that there are changes in the diameters of the different components of the rainwater drainage system, there will be changes in the budget for each scenario.

In a first approach, the analysis was focused on floors above ground, where the drainage system totally depends on rainfall intensity. It was concluded that differences in diameters do not result in a significant difference in the budget, which increases between 1,1% and 2,4% in the 3 regions considering the new IDF curves, as shown in the Table 7.

Table 7 - Budget comparison for a return period of 5 years

Region	A	B	C
IDF Curves LR23/95	16 569,90 €	16 205,09 €	16 815,36 €
New IDF curves	16 751,11 €	16 592,79 €	17 091,98 €
Total cost difference	181,21 €	387,69 €	276,62 €
Percentual cost difference	1,08%	2,34%	1,62%

For a return period of 10 years, the budget increases about 6% in the worst scenario (Table 8).

Table 8 - Budget comparison for a return period of 10 years

Region	A	B	C
IDF Curves LR23/95	16 749,49 €	16 592,79 €	17 033,00 €
New IDF curves	17 423,04 €	16 678,20 €	18 152,94 €
Total cost difference	673,55 €	85,41 €	1 119,94 €
Percentual cost difference	3,87%	0,51%	6,17%

In order to improve the assessment of the impact of climate change on building rainwater drainage systems, total costs should be considered, therefore the cost of the basement drainage system was added. The differences between total costs become even less representative. Tables 9 and 10 show that, for a return period of 5 years, the increase is around 1% with the new curves, whereas for a return period of 10 years, the budget increases can go up to 3,5%.

Table 9 - Total costs and comparison for a return period of 5 years

Regions	A		B		C	
IDF curve	DR23/95	New	DR23/95	New	DR23/95	New
Elevated floors cost (€)	16 569,90	16 751,11	16 205,09	16 592,79	16 815,36	17 091,98
Burried floors cost (€)	14 309,04					
Total cost (€)	30 878,93	31 060,15	30 514,13	30 901,83	31 124,40	31 401,02
Total cost difference (€)	181,21		387,69		276,62	
Percentual cost difference (%)	0,58		1,26		0,88	

Table 10 - Total costs and comparison for a return period of 10 years.

Region	A		B		C	
IDF Curves	DR23/95	New	DR23/95	New	DR23/95	New
Elevated floors cost (€)	16 749,49	17 423,04	16 592,79	16 678,20	17 033,00	18 152,94
Burried floors cost (€)	14 309,04					
Total cost (€)	31 058,23	31 732,08	30 901,83	30 987,24	31 342,03	32 461,98
Total cost difference (€)	673,55		85,41		1 119,94	
Percentual cost difference (%)	2,12		0,28		3,45	

The analysis shows that the rainfall intensity increase in the short duration precipitation is not relevant in the budget of building drainage systems, although it leads to the change of a significant part of the network in order to avoid system failures.

7. Conclusion

In order to assess whether climate change has an impact in building rainwater drainage systems, new IDF curves were built based on current precipitation data. The analysis of precipitation data has shown an increase of the rainfall intensity for short period precipitations (5, 10 and 15 minutes) and a decrease of the intensity in long precipitations (2,6 and 12 hours). These results show an alteration of the rainfall patterns.

Applicating of the new IDF curves in the design of building rainwater drainage systems lead to the increase of the diameters of some system components (pipes) when compared with the design made according to the current legislation. This proves that current regulations may be not able to cope with new patterns of precipitation and that might lead to system failures and building damages.

Finally, a budget analysis was also carried out to show that new IDF curves lead to an increased pipe diameters and costs. However, the cost increase is not significant, at least for studied case, and there is a significant part of the drainage system with altered diameters.

For a better understanding of the impacts of climate change a rainwater drainage system in buildings a larger number of buildings should be studied.

8. References

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