

Portuguese Climate Data for Building Simulation

2025 update



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1. Introduction

The weather is the most crucial exogenous factor determining the thermal behavior of a building as well as the performance of several of its technical systems, for instance HVAC (heating, ventilation, and air conditioning) and solar thermal or solar photovoltaic equipment.

The methods for assessment of thermal behavior and system performance have grown in detail and sophistication in parallel with the growth in speed and memory size of computers. Tabular data, correlations and other simplified methods gave place nowadays to numerical simulation. The availability of adequate weather data to serve as input to these methods has seldom been able to cope with their fast pace of progress. Spatial resolution, time resolution, and diversity of meteorological parameters have increased much since the 1950's, but even today the quality of weather data is perhaps the major source of uncertainty when assessing the performance of a building and its systems.

Building codes have also reflected this evolution of state-of-the-art, naturally with some lag. Initially, mean values were used, mostly monthly average temperature and mostly monthly average global solar radiation. This was easy to provide with existing meteorological stations for temperature; for global radiation, few stations existed but it was possible to establish correlations with sunshine hours, and these data were widely available. However, when methods progressed to use cumulative degree-days and radiation, then utilizability-type functions, then solar radiation on tilted planes, and finally, to use full-blown numerical simulations, observed data from the meteorological networks were no longer enough. Almost always it lacks either spatial resolution, or record length, or parameters measured, or all at once. In one way or another, providing data that is at least partially synthetic, becomes the only sensible solution.

By the 1990's the standard way to provide time series weather data in the context of building codes settled on the so-called "Typical Meteorological Years" (TMY) or one of its variations, like Reference Meteorological Years. TMYs use the concept of supplying an hourly time series covering one year, assembled from 12 monthly series, one for each calendar month, selected or built somehow in a manner that it reflects the long-term climate statistics for that month. It should contain all the parameters required for simulation. Ambient temperature, global solar radiation and diffuse or direct normal (beam) radiation are mandatory. From the global and diffuse or direct components of radiation, models can estimate the radiation on tilted planes, such as roofs, walls, windows, or solar panels. Other data often provided include: pressure, relative humidity (or equivalently, absolute humidity or dewpoint temperature), cloudiness (or sky cover or sunshine fraction), wind speed, wind direction, infrared radiation. Ancillary data not usually needed for building simulation can also be recorded, such as extraterrestrial radiation, solar position angles, precipitation, snow cover, snow depth, coded weather state.

There are numerous variants and combinations of criteria on how to select the "typical" monthly series that will be concatenated into a yearly series. One important remark is that national Weather Services tend to provide TMYs that are assembled giving the most weight to temperature and precipitation data. These must be assessed carefully as precipitation is of low relevance for the thermal performance of a building and its systems. Preferably, TMYs for building simulations should instead give preference to (temperature and) solar radiation.

Whatever the criteria adopted for selecting the monthly series, there are three major alternatives as regards the data itself:

- i. use measured data from a good quality reference station.

- ii. use data from numerical weather models.
- iii. use synthetic data assembled with statistical and stochastic methods.

Regarding the first option, the weather station to be selected is most often the closest one to the site but can be determined by climatic or administrative criteria. The instrumentation required must include a thermometer (which is a universal practice), a pyranometer (for global horizontal solar radiation) and either a pyranometer with a shadow band or shadow disk (for diffuse radiation), or a pyrliometer (for direct normal radiation). While since the 1990's most weather stations have included a pyranometer, it is still not common that they also include an instrument for diffuse or direct radiation measurements. Therefore, the respective data most often is estimated using models (correlations). Models must also be used to fill record gaps and substitute spurious data. Also note that it is necessary to provide periodic calibration, frequent cleaning, and good maintenance for instruments for radiation measurements, or else large bias occur that must be corrected *a posteriori*. For all those reasons, most often "measured" data series are in fact partially synthetic.

Regarding the second option, the land-atmosphere-ocean physical models solved by numerical algorithms initially did not provide good estimates of downward shortwave radiation. However, in the last decade, with progress in parameterization, spatial and time resolution, are now able to provide good quality radiation data. Particularly valuable for building and system simulations are datasets of referred as "reanalysis", obtained from weather forecasts run for the past ("hindcast" data), already having available the weather that was really experienced, from observed ground and satellite measurements. These datasets are therefore partially synthetic too.

Regarding the third option, fully synthetic time series, these are obtained from a cascade of statistical and stochastic methods run using as input monthly data only (and site coordinates). This approach is appealing because it is not expensive, requiring neither investments in weather stations networks, nor specialized human resources, nor large computing power. It does not suffer from problems with missing records or spatial resolution. By interpolating monthly data, one can obtain TMY for exactly the site and climate of interest. However, it does not represent all the complex variability and cross-correlation between meteorological parameters of real weather time series and tends to underestimate variability.

In summary, the best option for assembling TMYs depends on specific regional circumstances; plus, it has been changing during the last decades.

In the case of Portugal, consider that the European mainland roughly measures 550 km x 170 km and although it does not possess very high mountains, nevertheless it features at least seven climatic zones, not to mention numerous microclimates. In addition, there are the Madeira and Azores archipelagos in the North Atlantic, thus possessing yet another climate type. This diversity is so large and recognizable in the performance of Portuguese buildings and its systems, that national building codes had to allow for it.

For the 1990 building code, no TMYs were used in assessing building thermal performance, only monthly average temperature, cumulative degree-days, monthly average solar radiation onto various tilted planes, plus utilizability functions for estimating the production of solar thermal systems.

The 2006 and 2013 building codes (SCE 2006; 2013) required numerical simulation of commercial and services buildings (RSECE, 2006), as well as of solar systems – all this requiring TMYs. Due to lack of enough weather stations with data featuring enough quality, instruments, and record length, TMY climate datasets have been prepared using approach (iii), viz. synthetic series obtained from a "weather generator" that implemented a cascade of statistical relationships and stochastic time series models, developed, and calibrated for the region (Aguilar, 1996; 1998). A description of the TMY assembling

procedures for the 2006 building code is provided at Aguiar (2004 a; 2004 b). A summary of this 2006 process and extensive details for the case of the 2013 building code, can be found at Aguiar (2013).

For the 2020 revision of building codes, viz. the National Building Certification System (SCE, 2020), a new TMY scheme was developed: using approach (ii) became possible for the mainland, as TMY built from reanalysis of observed and hindcast meteorological fields, became available from the European Commission's Joint Research Centre (JRC) at Ispra, Italy (PVGIS, 2021, 2025). The new data was presented and discussed in the previous, original version of this document. However, the TMYs were not used in the 2020 revision of the building codes.

For the current 2025 revision of building codes, it is expected that the new TMYs do substitute the previous ones. Meanwhile, the NUTS III classification for Portugal was altered, splitting the Lisbon Metropolitan Area zone into the Greater Lisbon zone plus the Setúbal Peninsula zone. This required additional work of TMY preparation and reporting, which was the main reason for updating this document.

Section 2 provides a description of the TMY selection process for the mainland (for the Atlantic archipelagos, the 2013 TMYs remain valid). Section 3 addresses an elevation correction of temperature developed to enable some accounting of the geographical variability of the climate, as well as a climate change correction that is considered relevant considering the long lifetime of buildings. Section 4 presents the operational scheme for obtaining a TMY for a certain site and presents the user-friendly application that was developed for that purpose (SCE.CLIMA revised version 2.3).

2. Zone selection and TMY preparation

As mentioned in the Introduction, if for a certain site observed data are available, even if partially synthetic, it is preferable to use it rather than fully synthetic data from stochastic and statistical models, mainly because the former describes better the real-world variability. For instance, the stochastic TMYs provided for the 2013 building code (Aguar, 2013) represented the hourly data as smooth daily trends – which is generally enough for buildings with medium to high thermal inertia, but not for others. Also, autocorrelation and cross correlation of temperature and solar radiation are modelled up to one day lags only, which is acceptable for “normal” weather but does not allow to represent well in the time series phenomena such as long heat or cold waves.

Thus, when, good quality high-resolution meteorological reanalysis data became available in the last years, this was deemed better for assembling TMYs. However, these are massive datasets difficult to handle without specialized teams and powerful computing resources. Therefore, the work that the JRC has been performing in the last two decades was very important. The focus of PVGIS is research in solar resource assessment, photovoltaic (PV) performance studies, and the dissemination of knowledge and data about solar radiation and PV performance. An important result of this work is the online PVGIS web application (PVGIS, 2021, 2025), that can be used freely to estimate the performance of solar photovoltaic (PV) systems (it is now in version 5.3). But a large amount of research was done to make the results from PVGIS as accurate as possible, including in climatology.

In this context, JRC has mounted a TMY generator associated with PVGIS, following the procedure described in ISO 15927-4. The solar radiation database selected for the zone of Portugal was PVGIS-ERA5. The other meteorological variables, namely temperature, humidity, wind speed and direction, upward infrared radiation, and surface pressure, are obtained from the ERA-Interim reanalysis, a global atmospheric reanalysis that is available from 1 January 1979 to 31 August 2019 (ECMWF, 2021, 2025). This TMY tool can be used freely and interactively online.

The preparation of a scheme for assembling climatic for building regulations is not just a geophysical problem. To cover the Portuguese territory at a resolution of, say, 1 km², one would need to provide 92 212 TMY. Although it would not be strictly impossible, it is clearly not adequate for the overwhelming majority of practitioners in building regulations. Therefore, a conceptual approach was used whereby for each zone of interest, a reference TMY is provided, that is then adjusted for the specific site within the zone. The current section focuses on defining these zones and preparing the respective reference TMYs; the next section will deal with the adjustments.

The zones would be best defined by their climate, but from an operational, administrative viewpoint, using municipalities is much more convenient. Again, it would be possible to provide a reference TMY for each of the 308 Portuguese municipalities, however it is still considered too cumbersome at this point, and anyway, the underlying spatial resolution of the PVGIS data is not enough for developing spatial climate adjustment. The next administrative level is NUTS III; there are 26 in Portugal, as depicted in Figure 1, resulting in a manageable number of reference TMYs. Although NUTS III are defined using a logic of grouping municipalities according to their demographic and socio-economic characteristics, they also roughly share the same hydrographic basins, distance to coast, altitude bands, etc., all features that have connections to the geographic variations of climate. A further advantage of defining zones as NUTS III rather than municipalities, is that it prevents difficult to handle situations such like enclaves of some municipalities in other municipalities and having very small along with very large zones.



Figure 1 - The Portuguese mainland NUTS III (2024 version).

Table 1 provides a list of municipalities for each NUTS III, along with the minimum ($h_{\min}$) and the maximum ($h_{\max}$) elevation for each municipality. The later information is relevant from an operational viewpoint, for validation purposes, enabling to check that the site elevation specified by a user is within the elevation range of the respective municipality.

Table 1 - List of Portuguese municipalities with NUTS III and elevation range data.

NUTS III	Município	$h_{\min}$	$h_{\max}$
Alto Minho	Vila Nova de Cerveira	0	638
	Valença	0	784
	Caminha	0	805
	Viana do Castelo	0	823
	Ponte de Lima	3	835
	Monção	9	1114
	Arcos de Valdevez	17	1416
	Melgaço	25	1336
	Ponte da Barca	25	1359
Cávado	Paredes de Coura	125	883
	Esposende	0	281
	Barcelos	9	488
	Vila Verde	21	789
	Braga	22	572
	Amares	24	901
	Terras de Bouro	75	1525

Table 1 - List of Portuguese municipalities with NUTS III and elevation range data. (continued)

NUTS III	Município	h_{min}	h_{max}
Ave	Vila Nova de Famalicão	25	462
	Póvoa de Lanhoso	50	743
	Vieira do Minho	75	1262
	Guimarães	83	613
	Mondim de Basto	100	1307
	Vizela	125	478
	Cabeceiras de Basto	150	1200
	Fafe	175	894
Alto Tâmega	Ribeira de Pena	153	1286
	Montalegre	175	1527
	Valpaços	225	1148
	Vila Pouca de Aguiar	225	1205
	Boticas	250	1270
	Chaves	300	1050
Terras de Trás-os-Montes	Vila Flor	123	837
	Mogadouro	150	997
	Alfândega da Fé	150	1199
	Mirandela	175	941
	Macedo de Cavaleiros	225	1263
	Vimioso	250	955
	Vinhais	275	1273
	Bragança	325	1489
	Miranda do Douro	400	911
Área Metropolitana do Porto	Espinho	0	100
	Matosinhos	0	134
	Porto	0	157
	Póvoa de Varzim	0	202
	Vila do Conde	0	235
	Vila Nova de Gaia	0	262
	Gondomar	5	470
	Trofa	25	250
	Santa Maria da Feira	25	450
	Paredes	25	519
	Oliveira de Azeméis	25	645
	Maia	35	255
	Santo Tirso	36	535
	Valongo	50	385
	Arouca	50	1222
	Vale de Cambra	75	1046
	São João da Madeira	150	276

Table 1 - List of Portuguese municipalities with NUTS III and elevation range data. (continued)

NUTS III	Município	h_{min}	h_{max}
Tâmega e Sousa	Marco de Canaveses	8	962
	Cinfães	12	1381
	Penafiel	22	586
	Castelo de Paiva	25	694
	Resende	50	1218
	Amarante	50	1348
	Baião	50	1416
	Celorico de Basto	75	851
	Felgueiras	145	575
	Paços de Ferreira	175	570
	Lousada	175	578
Douro	Mesão Frio	50	1038
	Lamego	50	1122
	Peso da Régua	50	1397
	Carrazeda de Ansiães	75	898
	Armamar	75	955
	Tabuaço	75	985
	São João da Pesqueira	75	994
	Alijó	75	1000
	Sabrosa	75	1100
	Santa Marta de Penaguião	75	1416
	Vila Nova de Foz Côa	82	814
	Torre de Moncorvo	100	920
	Freixo de Espada à Cinta	124	885
	Vila Real	125	1350
	Murça	175	1031
	Tarouca	325	1102
	Moimenta da Beira	375	1011
	Penedono	450	1000
	Sernancelhe	475	964
Região de Aveiro	Murtosa	0	17
	Ílhavo	0	61
	Vagos	0	68
	Aveiro	0	78
	Estarreja	0	130
	Ovar	0	225
	Albergaria-a-Velha	0	425
	Águeda	4	762
	Oliveira do Bairro	5	78
	Anadia	13	525
	Sever do Vouga	25	841

Table 1 - List of Portuguese municipalities with NUTS III and elevation range data. (continued)

NUTS III	Município	h_{min}	h_{max}
Viseu - Dão - Lafões	Oliveira de Frades	50	1062
	São Pedro do Sul	75	1119
	Vouzela	125	1043
	Tondela	133	1075
	Santa Comba Dão	137	352
	Carregal do Sal	150	375
	Nelas	150	484
	Viseu	200	899
	Castro Daire	200	1375
	Mangualde	225	766
	Penalva do Castelo	325	724
	Sátão	375	859
	Aguiar da Beira	450	989
	Vila Nova de Paiva	550	1036
Beiras e Serra da Estrela	Figueira de Castelo Rodrigo	124	976
	Pinhel	150	926
	Seia	175	1993
	Mêda	225	945
	Gouveia	250	1626
	Fundão	275	1227
	Fornos de Algodres	325	915
	Celorico da Beira	375	1256
	Covilhã	375	1993
	Trancoso	425	986
	Guarda	441	1287
	Belmonte	446	890
	Sabugal	450	1223
	Almeida	500	845
	Manteigas	518	1993
Região de Coimbra	Mira	0	64
	Cantanhede	0	137
	Figueira da Foz	0	257
	Montemor-o-Velho	2	127
	Soure	6	532
	Coimbra	9	500
	Condeixa-a-Nova	12	466
	Mealhada	25	568
	Penacova	36	550
	Vila Nova de Poiares	42	458
	Miranda do Corvo	50	940
	Mortágua	75	768
	Lousã	75	1205
	Arganil	75	1418
	Tábua	143	518
	Penela	150	873
	Góis	150	1204
	Oliveira do Hospital	150	1244
	Pampilhosa da Serra	300	1418

Table 1 - List of Portuguese municipalities with NUTS III and elevation range data. (continued)

NUTS III	Município	h_{min}	h_{max}
Região de Leiria	Marinha Grande	0	165
	Leiria	0	410
	Pombal	0	560
	Batalha	50	523
	Porto de Mós	50	615
	Alvaiázere	96	618
	Figueiró dos Vinhos	125	1009
	Pedrógão Grande	150	779
	Ansião	175	533
	Castanheira de Pêra	350	1205
Médio Tejo	Torres Novas	13	678
	Abrantes	18	317
	Vila Nova da Barquinha	19	201
	Constância	22	224
	Entroncamento	25	87
	Tomar	32	350
	Alcanena	43	678
	Mação	47	643
	Sardoal	75	452
	Ourém	95	678
	Ferreira do Zêzere	125	451
	Vila de Rei	125	594
	Sertã	125	1084
Beira Baixa	Vila Velha de Ródão	50	570
	Proença-a-Nova	114	954
	Castelo Branco	121	1227
	Idanha-a-Nova	125	828
	Oleiros	250	1085
	Penamacor	300	1076
Oeste	Peniche	0	165
	Nazaré	0	177
	Lourinhã	0	201
	Óbidos	0	222
	Caldas da Rainha	0	255
	Torres Vedras	0	394
	Alcobaça	0	504
	Alenquer	2	666
	Bombarral	11	205
	Arruda dos Vinhos	44	395
	Cadaval	46	665
	Sobral de Monte Agraço	125	442

Table 1 - List of Portuguese municipalities with NUTS III and elevation range data. (continued)

NUTS III	Município	h_{min}	h_{max}
Lezíria do Tejo	Benavente	0	78
	Salvaterra de Magos	2	105
	Azambuja	2	194
	Cartaxo	3	130
	Santarém	3	529
	Almeirim	5	171
	Coruche	7	264
	Alpiarça	9	132
	Chamusca	11	200
	Golegã	14	95
	Rio Maior	25	497
Alto Alentejo	Ponte de Sor	46	285
	Gavião	50	312
	Nisa	50	463
	Avis	75	245
	Castelo de Vide	125	825
	Alter do Chão	147	413
	Fronteira	150	371
	Crato	150	445
	Sousel	150	454
	Elvas	150	496
	Campo Maior	173	341
	Marvão	200	1027
	Monforte	225	402
	Arronches	236	584
	Portalegre	250	1027
Grande Lisboa	Oeiras	0	199
	Lisboa	0	228
	Vila Franca de Xira	0	378
	Loures	0	409
	Mafra	0	431
	Cascais	0	475
	Sintra	0	528
	Odivelas	24	339
Península de Setúbal	Amadora	50	258
	Moita	0	58
	Alcochete	0	61
	Barreiro	0	76
	Seixal	0	81
	Almada	0	125
	Montijo	0	135
	Sesimbra	0	380
	Palmela	0	391
	Setúbal	0	501
	Sintra	0	528

Table 1 - List of Portuguese municipalities with NUTS III and elevation range data. (continued)

NUTS III	Município	h_{min}	h_{max}
Alentejo Central	Vendas Novas	25	190
	Montemor-o-Novo	25	424
	Mora	38	206
	Viana do Alentejo	72	374
	Mourão	100	286
	Reguengos de Monsaraz	100	363
	Portel	100	424
	Alandroal	111	416
	Arraiolos	150	412
	Évora	150	441
	Vila Viçosa	165	475
	Redondo	187	653
	Estremoz	205	653
	Borba	250	550
Alentejo Litoral	Sines	0	250
	Alcácer do Sal	0	254
	Grândola	0	325
	Santiago do Cacém	0	370
	Odemira	0	515
Baixo Alentejo	Ferreira do Alentejo	24	277
	Beja	25	284
	Mértola	25	371
	Serpa	25	523
	Aljustrel	63	258
	Ourique	65	377
	Vidigueira	75	412
	Moura	75	584
	Alvito	100	315
	Castro Verde	125	288
	Barrancos	125	412
	Cuba	150	309
	Almodôvar	150	577
Algarve	Lagoa	0	103
	Vila do Bispo	0	156
	Vila Real de Santo António	0	225
	Albufeira	0	227
	Lagos	0	255
	Castro Marim	0	276
	Portimão	0	325
	Aljezur	0	370
	Faro	0	410
	Olhão	0	410
	Silves	0	426
	Tavira	0	541
	Loulé	0	589
	Alcoutim	25	379
	Monchique	25	902
	São Brás de Alportel	125	530

Table 1 - List of Portuguese municipalities with NUTS III and elevation range data. (continued)

NUTS III	Município	h_{min}	h_{max}
Região Autónoma dos Açores	Santa Cruz da Graciosa	0	402
	Vila do Porto	0	587
	Corvo	0	718
	Vila da Praia da Vitória	0	808
	Lajes das Flores	0	830
	Ponta Delgada	0	873
	Ribeira Grande	0	877
	Santa Cruz das Flores	0	914
	Calheta	0	942
	Lagoa	0	947
	Vila Franca do Campo	0	947
	Angra do Heroísmo	0	1021
	Horta	0	1043
	Velas	0	1053
	Nordeste	0	1103
	Povoação	0	1103
	Lajes do Pico	0	2351
	Madalena	0	2351
	São Roque do Pico	0	2351
Região Autónoma da Madeira	Porto Santo	0	517
	Santa Cruz	0	1415
	Machico	0	1480
	Ponta do Sol	0	1620
	Calheta	0	1640
	Porto Moniz	0	1640
	Ribeira Brava	0	1725
	São Vicente	0	1725
	Funchal	0	1818
	Câmara de Lobos	0	1862
	Santana	0	1862

The next step is to assign reference coordinates for each NUTS III. The process adopted is illustrated in Figure 2. Rectangles defined by the extreme coordinates of the borders of each NUTS III are drawn, and the geographical coordinates of the center are extracted: latitude, longitude, and elevation.

As already mentioned, for the case of the two Atlantic archipelagoes of Azores and Madeira, the scheme adopted in the SCE 2013 was maintained (these zones are not depicted in Figure 2). The numerical data for the reference coordinates are provided at Table 2.

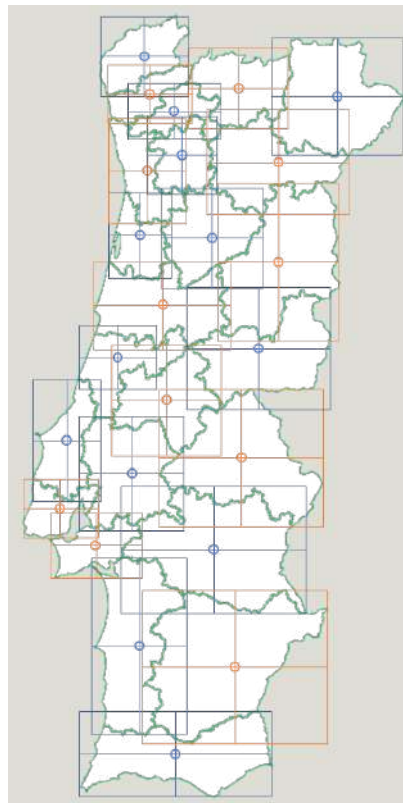


Figure 2 – Assigning reference coordinates to mainland NUTS III.

Table 2 – Reference coordinates assigned for each NUTS III.

NUTS III	Reference latitude [°N]	Reference longitude [°W]	Reference elevation [m]
Alto Minho	41.92	-8.49	624
Cávado	41.65	-8.40	65
Ave	41.54	-8.19	425
Alto Tâmega	41.67	-7.66	545
Terras de Trás-os-Montes	41.58	-6.74	636
Área Metropolitana do Porto	41.22	-8.42	221
Tâmega e Sousa	41.34	-8.04	310
Douro	41.13	-7.25	586
Região de Aveiro	40.82	-8.46	281
Viseu Dão Lafões	40.72	-7.85	437
Beiras e Serra da Estrela	40.67	-7.32	511
Região de Coimbra	40.29	-8.32	333
Região de Leiria	38.84	-8.75	147
Médio Tejo	39.63	-8.21	200
Beira Baixa	39.97	-7.50	375
Oeste	39.31	-9.12	170
Lezíria do Tejo	39.12	-8.56	35
Alto Alentejo	39.25	-7.80	153
Grande Lisboa	38.77	-9.21	48
Península de Setúbal	38.57	-9.05	35
Alentejo Central	38.56	-7.98	256
Alentejo Litoral	37.96	-8.46	103
Baixo Alentejo	37.80	-7.70	131
Algarve	37.28	-8.19	236
Região Autónoma dos Açores	37.82	27.75	10
Região Autónoma da Madeira	32.65	16.90	380

Next, 26 reference TMY were extracted using the tool available at the PVGIS website. The TMY for the two Atlantic archipelagoes were the same as those of the SCE 2013, generation procedure described in Aguiar (2013).

3. Adjusting for elevation and climate change

3.1. Temperature dependence on elevation

Having the reference TMY available for the NUTS III of interest, the meteorological data needs to be adjusted for the major climatic patterns prevailing in that zone. In the case of Portugal, elevation and distance to coast were identified as the major parameters explaining climatic variability. As elevation roughly grows with distance to coast for most NUTS III having a coastal border (check Figure 3), it becomes the major parameter to use in adapting the reference TMY.

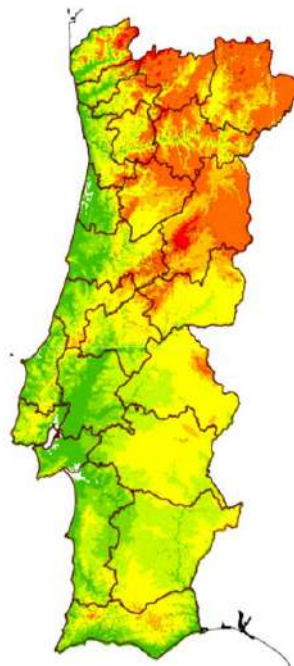


Figure 3 – NUTS III and orography of mainland Portugal.

This was checked for the case of temperature data by an analysis that is summarized at Table 4. It depicts, for each NUTS III, statistics extracted from TMY obtained at 50 m, 200 m and then at 200 m intervals, for heating degree-days base 18 °C (HDD), mean Summer temperature (T_{JJAS}) and summer and winter zones (defined as in Table 3), again confirming the decisive impact of elevation as found in previous studies (Aguar, 2013), although more so for some zones than others. This analysis showed also that the gradient of temperature vs. elevation is specific to each zone.

Table 3 - Criteria for identifying SCE summer and winter zones.

Winter zone	I1	I2	I3
Criteria	$HDD \leq 1300 \text{ }^{\circ}\text{C}$	$1300 \text{ }^{\circ}\text{C} < HDD \leq 1800 \text{ }^{\circ}\text{C}$	$HDD > 1800 \text{ }^{\circ}\text{C}$
Summer zone	V1	V2	V3
Criteria	$T_{JJAS} \leq 20 \text{ }^{\circ}\text{C}$	$20 \text{ }^{\circ}\text{C} < T_{JJAS} \leq 22 \text{ }^{\circ}\text{C}$	$T_{JJAS} > 22 \text{ }^{\circ}\text{C}$

Table 4 - Analysis of the impact of elevation on climate statistics for each NUTS III.

NUTS III	Elevation	HDD (°C)	T _{JJAS} (°C)	Winter zone	Summer zone
Área Metropolitana do Porto	50	1209	22.1	1	3
	200	1323	21.9	2	2
	400	1481	21.6	2	2
	600	1641	21.3	2	2
	800	1801	21.1	3	2
	1000	1961	20.8	3	2
	1200	2121	20.5	3	2
Grande Lisboa	50	840	21,5	1	2
	200	836	21,5	1	2
	400	830	21,6	1	2
Península de Setúbal	50	753	21,8	1	2
	200	752	21,9	1	2
	400	750	22,1	1	3
Alentejo Central	200	1118	23.9	1	3
	400	1296	23.6	1	3
Alentejo Litoral	50	878	22.2	1	3
	200	980	22.3	1	3
	400	1123	22.4	1	3
Algarve	200	726	24.3	1	3
Alto Alentejo	200	996	24.6	1	3
	400	1147	24.2	1	3
Alto Minho	50	1160	21.7	1	2
	200	1312	21.5	2	2
	400	1529	21.1	2	2
	600	1749	20.8	2	2
	800	1970	20.4	3	2
	1000	2190	20.1	3	2
	1200	2411	19.7	3	1
Alto Tâmega	200	1501	20.5	2	2
	400	1727	19.9	2	1
	600	1958	19.3	3	1
	800	2191	18.7	3	1
	1000	2423	18.1	3	1
	1200	2655	17.5	3	1
Ave	50	1344	23.1	2	3
	200	1524	22.7	2	3
	400	1775	22.3	2	3
	600	2035	21.8	3	2
	800	2299	21.4	3	2
	1000	2564	21.0	3	2
	1200	2830	20.5	3	2
Baixo Alentejo	200	950	24.5	1	3

Table 4 - Analysis of the impact of elevation on climate statistics for each NUTS III.(continued)

NUTS III	Elevation	HDD (°C)	T _{JJAS} (°C)	Winter zone	Summer zone
Beira Baixa	200	1181	25.7	1	3
	400	1366	25.2	2	3
	600	1567	24.7	2	3
	800	1777	24.2	2	3
	1000	1993	23.7	3	3
	1200	2213	23.2	3	3
Beiras e Serra da Estrela	200	1251	23.0	1	3
	400	1433	22.6	2	3
	600	1628	22.2	2	3
	800	1837	21.8	3	2
	1000	2054	21.4	3	2
	1200	2274	20.9	3	2
	1400	2495	20.5	3	2
	1600	2715	20.1	3	2
	1800	2935	19.7	3	1
Cávado	50	1085	21.9	1	2
	200	1225	21.6	1	2
	400	1424	21.2	2	2
	600	1639	20.7	2	2
	800	1856	20.3	3	2
	1000	2074	19.9	3	1
	1200	2291	19.5	3	1
	1400	2509	19.1	3	1
Douro	50	1339	23.9	2	3
	200	1495	23.4	2	3
	400	1710	22.7	2	3
	600	1932	22.0	3	3
	800	2155	21.3	3	2
	1000	2380	20.7	3	2
	1200	2604	20.0	3	1
Lezíria do Tejo	50	1086	23.7	1	3
	200	1274	23.6	1	3
	400	1536	23.4	2	3
Médio Tejo	50	1182	23.4	1	3
	200	1312	23.2	2	3
	400	1495	22.9	2	3
	600	1692	22.6	2	3
	800	1899	22.4	3	3

Table 4 - Analysis of the impact of elevation on climate statistics for each NUTS III. (continued)

NUTS III	Elevation	HDD (°C)	T _{JJAS} (°C)	Winter zone	Summer zone
Oeste	50	1022	20.9	1	2
	200	1177	20.7	1	2
	400	1391	20.4	1	2
	600	1606	20.1	2	2
Região de Aveiro	50	1059	21.9	1	2
	200	1184	21.7	1	2
	400	1371	21.5	2	2
	600	1565	21.3	2	2
	800	1759	21.1	2	2
Região de Coimbra	50	1068	21.6	1	2
	200	1227	21.5	1	2
	400	1466	21.3	2	2
	600	1714	21.1	2	2
	800	1968	20.9	3	2
	1000	2222	20.7	3	2
	1200	2476	20.5	3	2
	1400	2730	20.3	3	2
Região de Leiria	50	1087	20.6	1	2
	200	1293	20.2	1	2
	400	1581	19.7	2	1
	600	1869	19.2	3	1
	800	2159	18.6	3	1
	1000	2449	18.1	3	1
	1200	2739	17.6	3	1
Regiões Autónomas	50	253	22.5	1	3
	200	635	20.8	1	2
	400	813	18.7	1	1
	600	1003	18.6	1	1
	800	1198	17.5	1	1
	1000	1396	16.4	2	1
	1200	1595	15.3	2	1
	1400	1794	14.2	2	1
	1600	1993	13.1	3	1
	1800	2192	12.0	3	1
	2000	2391	10.9	3	1
Tâmega e Sousa	50	1275	20.9	1	2
	200	1359	20.7	2	2
	400	1475	20.5	2	2
	600	1593	20.3	2	2
	800	1711	20.1	2	2
	1000	1830	19.9	3	1
	1200	1948	19.6	3	1

Table 4 - Analysis of the impact of elevation on climate statistics for each NUTS III.(continued)

NUTS III	Elevation	HDD (°C)	T _{JJAS} (°C)	Winter zone	Summer zone
Terras de Trás-os-Montes	200	1459	24.4	2	3
	400	1676	23.2	2	3
	600	1899	22.0	3	3
	800	2128	20.8	3	2
	1000	2360	19.7	3	1
	1200	2592	18.5	3	1
	1400	2824	17.3	3	1
Viseu-Dão-Lafões	200	1241	21.9	1	2
	400	1406	21.4	2	2
	600	1579	20.8	2	2
	800	1759	20.3	2	2
	1000	1947	19.7	3	1
	1200	2137	19.2	3	1

Regarding solar radiation, no such strong dependence on altitude was found in the data. In principle global solar radiation should increase somewhat with altitude (or more precisely as the optical depth decreases), as the radiation needs to travel along a shorter path, suffering less diffraction and dispersion from aerosols. This would be significant at a scale of a few km, however, for most of the NUTS III, the elevation range is too short for this to be clearly seen in the data. Another issue is related to the effect of cloud layers. The typical cloud base could stand below the higher elevation areas of a NUTS III, so these would receive more radiation than the lower layers. Unfortunately, the data available was not enough to examine and quantify this effect. Therefore, no correction is proposed for reference TMY radiation data.

The remaining parameters in the TMY – pressure, relative humidity, wind speed and direction – have less impact in the thermal behavior of a building than temperature and radiation. Also, except for pressure, that can easily be adjusted if needed, there is not enough data to study and provide an elevation correction, so no corrections are proposed. In conclusion, the only modification proposed for the reference TMYs is an adjustment of temperature with elevation.

Previous studies with different observed datasets (e.g. Aguiar, 2013) have found that the dispersion of the relationship between monthly or daily temperature with elevation to be very large. Therefore, only a simple additive linear adjustment is reasonable, as expressed in Equation (1) below,

$$T(t) = T_{\text{REF}}(t) + a(t) (h - h_{\text{REF}}) \quad (1)$$

where t represents the time and h is elevation.

In SCE 2013, the slope coefficient a was an average value valid for the entire year. However, a look of the TMY data at a regularly spaced grid revealed a significant seasonal variation of the slope for many of the NUTS III. This can be easily understood in geophysical terms, at least for those NUTS III with a coastal border: the mean ocean temperature is much more stable throughout the year than mean inland temperature, causing an average gradient ocean-land that should depend on season.

This called for a detailed investigation of the temperature correction proposed for SCE 2020, now written as in Equation (2) below:

$$T = T_{\text{REF}} + a(m) (h - h_{\text{REF}}) \quad (2)$$

where m refers to the calendar month.

The results of the study are provided at Table 5. Positive values in the table are highlighted; an interpretation for those is that, as elevation is being used as a proxy to distance-to-coast, in the warmer months of the year the gradient can be close to null or even reversed – meaning that the most interior areas of the NUTS III, despite laying at higher altitudes, can be hotter than those near the coast.

The large dispersion of the data points translated in high uncertainty; therefore, the slope estimates were rounded to the closest 0.5 interval and were limited to the range -10 to 2. The highest values in the tabled data must not be naïvely interpreted as strong temperature gradients in the corresponding NUTS III. Indeed, the gradients can be shallow if the elevation range is short (it is for instance the case of ‘Lezíria do Tejo’). Note also that the NUTS III with costal borders tend, as expected, to display higher seasonality than those at the interior at similar latitude – compare e.g. ‘Alto Minho’ with ‘Terras de Trás-os-Montes’, or ‘Alentejo Litoral’ with ‘Baixo Alentejo’. Nevertheless, some features of the data result from characteristics of the reanalysis dataset and its spatial resolution, as well as from the TMY production process at PVGIS; so, it is no use to try to push this type of analysis much further.

Table 5 - Slope of the seasonal temperature correction.

NUTS III	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alto Minho	-7.5	-7.0	-6.0	-5.0	-3.5	-1.5	1.0	0.0	-2.5	-5.5	-7.0	-8.0
Cávado	-7.0	-7.0	-6.0	-5.5	-4.0	-2.0	0.5	-0.5	-3.0	-5.5	-6.5	-7.0
Ave	-9.5	-9.0	-7.0	-5.5	-3.5	0.0	0.0	0.0	-2.5	-6.5	-9.0	-10.0
Alto Tâmega	-7.0	-7.0	-6.5	-6.0	-5.0	-3.5	0.0	-2.0	-4.0	-6.0	-7.0	-7.0
Terras de Trás-os-Montes	-6.0	-7.0	-7.0	-6.5	-7.0	-6.5	-6.0	-5.5	-6.0	-6.0	-6.0	-5.0
Área Metropolitana do Porto	-5.0	-5.0	-4.5	-4.0	-2.5	-1.0	0.5	0.0	-2.0	-4.0	-5.0	-5.5
Tâmega e Sousa	0.0	-6.5	-5.5	-5.0	-3.0	0.0	0.0	0.0	0.0	-4.5	0.0	0.0
Douro	-6.5	-7.0	-6.5	-6.0	-5.0	-4.0	0.0	-3.0	-4.5	-6.0	-6.5	-6.5
Região de Aveiro	-8.5	-7.5	-4.5	-3.0	0.0	0.0	0.0	0.0	0.0	-4.0	-7.5	-9.5
Viseu Dão Lafões	-5.5	-6.0	-5.5	-5.0	-4.0	-3.0	0.0	-2.0	-4.0	-5.0	-5.5	-5.5
Beiras e Serra da Estrela	-7.0	-6.5	-6.0	-5.5	-5.0	-3.0	0.0	0.0	-3.0	-5.5	-6.5	-7.0
Região de Coimbra	-9.0	-8.5	-6.5	-5.5	-3.5	0.0	2.0	2.0	-2.0	-6.0	-8.5	-9.5
Região de Leiria	-10.0	-10.0	-8.0	-6.0	-4.0	0.0	0.0	0.0	-3.0	-7.5	-10.0	-10.0
Médio Tejo	-9.0	-8.0	-6.0	-4.5	0.0	0.0	0.0	0.0	0.0	-5.5	-8.0	-9.0
Beira Baixa	-6.5	-6.5	-6.0	-5.5	-5.5	-3.5	0.0	0.0	-4.0	-6.0	-6.5	-6.5
Oeste	-8.0	-7.5	-5.5	-4.0	-2.5	0.0	0.0	0.0	0.0	-5.5	-7.5	-8.5
Lezíria do Tejo	-10.0	-10.0	-8.5	-5.0	0.0	0.0	2.0	2.0	0.0	-7.5	-10.0	-10.0
Alto Alentejo	-6.0	-6.0	-5.0	-4.5	-4.0	-2.0	0.0	0.0	-3.5	-5.0	-5.5	-5.0
Grande Lisboa	0.0	1.0	0.0	0.0	-0.5	0.5	0.5	0.0	0.5	0.0	0.0	0.5
Península de Setúbal	4.0	0.5	-1.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	0.0	1.0
Alentejo Central	-8.5	-8.0	-5.5	-4.0	0.0	0.0	0.0	0.0	0.0	-5.0	-8.5	-8.5
Alentejo Litoral	-6.0	-6.0	-5.0	-3.5	-1.0	2.0	2.0	2.0	1.0	-3.5	-5.5	-5.5
Baixo Alentejo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Algarve	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Região Autónoma dos Açores	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5
Região Autónoma da Madeira	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5

3.2. Climate change impacts

As the lifetime of buildings is large, climate change effects should not be ignored. Another seasonally dependent additive correction $\Delta T_{cc}(m)$ was developed, very similar to the used already used for the SCE 2013. It is based on the results of the Coupled Model Intercomparison Project Phase 5 (CMIP5), for the RCP 4.5 emissions scenario (see CMIP5, 2012; Meinshausen et al., 2011), that considering the recent progress under the Climate Change Paris Agreement seems now more likely than the more severe RCP 8.5 scenario.

The average warming for the period 2021-2060 (40 years), relative to the 1971-2000 baseline, is of the order of 1.2 °C, however not uniform over mainland Portugal area (cf. IPMA, 2013), being more severe in the interior areas than at the coastal areas. For providing a simplified correction, the mainland NUTS III were grouped into three regions of impact, as shown in Figure 4, and a seasonal trend was computed using more detailed data downloaded from the KNMI Climate Explorer (KNMI, 2012). The results are provided in Table 6.

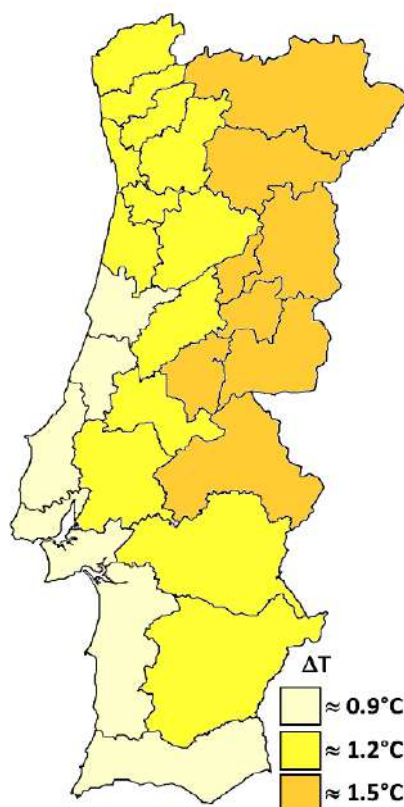


Figure 4 - Simplified mean temperature anomalies with the RCP 4.5 scenario for 2021-2060.

Table 6 - Climate change seasonal temperature correction.

NUTS III	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alto Minho	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Cávado	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Ave	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Alto Tâmega	0.9	0.8	0.9	1.1	1.4	1.8	1.9	1.9	1.8	1.4	1.0	0.9
Terras de Trás-os-Montes	0.9	0.8	0.9	1.1	1.4	1.8	1.9	1.9	1.8	1.4	1.0	0.9
Área Metropolitana do Porto	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Tâmega e Sousa	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Douro	0.9	0.8	0.9	1.1	1.4	1.8	1.9	1.9	1.8	1.4	1.0	0.9
Região de Aveiro	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Viseu Dão Lafões	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Beiras e Serra da Estrela	0.9	0.8	0.9	1.1	1.4	1.8	1.9	1.9	1.8	1.4	1.0	0.9
Região de Coimbra	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Região de Leiria	0.4	0.4	0.5	0.6	0.7	1.0	1.1	1.0	1.0	0.7	0.5	0.4
Médio Tejo	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Beira Baixa	0.9	0.8	0.9	1.1	1.4	1.8	1.9	1.9	1.8	1.4	1.0	0.9
Oeste	0.4	0.4	0.5	0.6	0.7	1.0	1.1	1.0	1.0	0.7	0.5	0.4
Lezíria do Tejo	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Alto Alentejo	0.9	0.8	0.9	1.1	1.4	1.8	1.9	1.9	1.8	1.4	1.0	0.9
Grande Lisboa	0.4	0.4	0.5	0.6	0.7	1.0	1.1	1.0	1.0	0.7	0.5	0.4
Península de Setúbal	0.4	0.4	0.5	0.6	0.7	1.0	1.1	1.0	1.0	0.7	0.5	0.4
Alentejo Central	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Alentejo Litoral	0.4	0.4	0.5	0.6	0.7	1.0	1.1	1.0	1.0	0.7	0.5	0.4
Baixo Alentejo	0.7	0.6	0.7	0.8	1.0	1.4	1.5	1.5	1.4	1.0	0.8	0.7
Algarve	0.4	0.4	0.5	0.6	0.7	1.0	1.1	1.0	1.0	0.7	0.5	0.4
Região Autónoma dos Açores	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.4	0.3	0.2
Região Autónoma da Madeira	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.4	0.3	0.2

4. Obtaining and using the TMY data

Considering the methods and results of sections 2 and 3, the scheme for obtaining the TMY for a certain site is the following step-by-step:

- i. Set municipality
- ii. Find the corresponding NUTS III (use Table 1)
- iii. Obtain the reference elevation h_{REF} for that NUTS III (use Table 2)
- iv. Set site elevation h (use Table 1 to check if it is within the elevation range)
- v. Get the reference TMY for that NUTS III
- vi. For each month m :
 - compute the elevation correction $\Delta T_h(m) = a(m)(h - h_{REF})$ (use Table 5)
 - compute the climate change correction $\Delta T_{CC}(m)$ (use Table 6)
 - add $\Delta T_h(m) + \Delta T_{CC}(m)$ to each hourly temperature value of that monthly time series.

With this method there will be of course some discontinuities at the interface of the calendar months, but they will be small. To obtain the reference TMY just set the elevation as equal to the reference (h_{REF}).

A user-friendly software for implementing this scheme was developed, the SCE-CLIMA application. It is mounted over EXCEL and is currently at version 2.3. The output TMYs are provided in the EPW (EnergyPlus Weather) format. An aspect of the interface of SCE-CLIMA is show in Figure 5. The software is freely available at the DGEG website¹, www.dgeg.gov.pt.

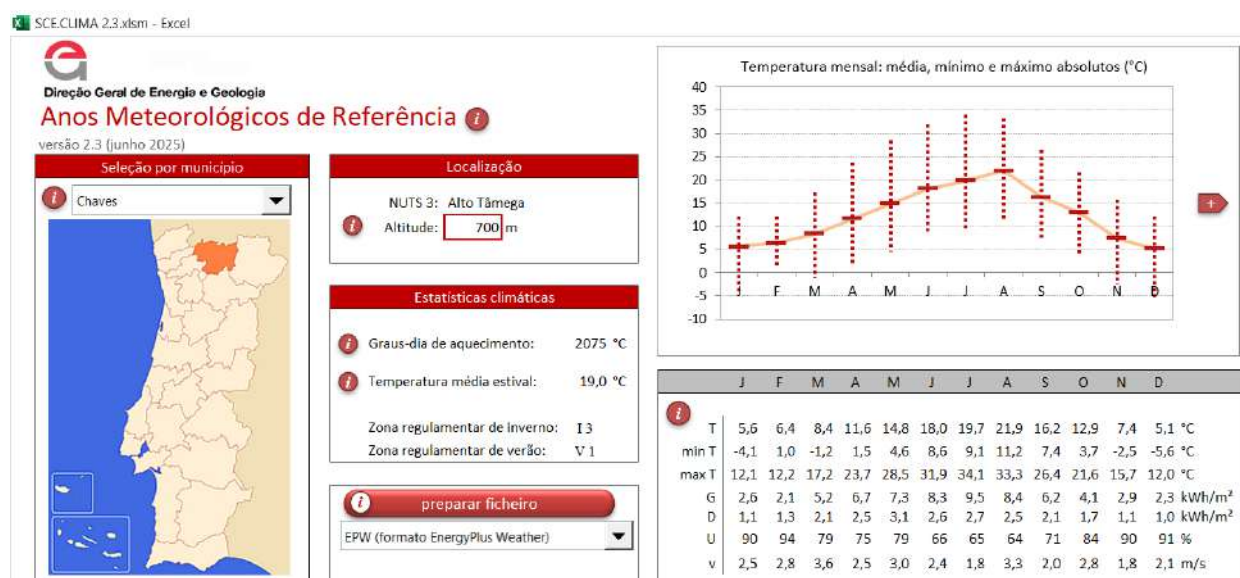


Figure 5 - Interface of SCE-CLIMA 2.3.

¹ Currently at webpage <https://www.dgeg.gov.pt/pt/areas-setoriais/energia/energias-renovaveis-e-sustentabilidade/sce-er/>

To finalize, some relevant observations regarding the use of this TMY data.

The TMY data can also be useful outside the framework of the Building Certification System, for numerical simulation of buildings as well as for solar thermal and PV systems, including those not located onto buildings.

However, these data should not be used directly for purposes such as simulating natural ventilation, or micro-wind turbines. This is because the wind data are (i) provided for the reference NUTS III coordinates, not the site location and (ii) corresponds to an obstacle-free situation, not an urban or semi-urban context.

Also be aware that high obstructions of the horizon can call for a correction of the radiation data, especially on clear sky days. The simple correction suggested is to set the beam radiation value to zero when the sun disk is being obstructed, reduce the diffuse radiation value in 20% as an approximation, and recompute the global value. This scheme may seem too crude; however, notice that it does not impact on overcast or on most cloudy days; and that even on clear days, it very rarely impacts on the periods when the sun is high in the sky and that accounts for most of the daily irradiation. Therefore, in practice it is an effective correction.

It is remarked also that the TMY concept is to provide a single yearly time series corresponding to a sort of average climatic conditions. Therefore, it does not represent well long-term weather extremes. One implication is that a yearly simulation of a building or technical system will not go through all the weather variability that will be experienced during the lifetime of the building or system. For that to happen, simulations with about 5 to 10 years would typically be necessary.

As a corollary, TMY data should be used with caution when sizing technical systems. For instance, HVAC are for the most part sized for heating using conditions for a very overcast and cool day; and sized for cooling, using conditions for a very hot and sunny day. Even scanning the TMY to find and use the most extreme days in the time series, the odds are that this leads to underestimation of the real climatic extremes. Work to prepare extreme days suitable for system sizing is under way at DGEG.

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