The performance of Innovative Building Technologies in South Africa's Climatic Zones

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1. Introduction

This chapter quantifies the thermal performance of a cross section of Innovative Building Technologies (IBT) in South Africa's climatic zones. An IBT in the context of this chapter means a South African Agrément certified building system, but the term excludes masonry, that is currently predominantly used in South Africa. A misconception exists that IBT's are inferior to masonry construction and furthermore that heavy weight construction such as masonry is preferable within the South African context.

Previous chapters, Maximising the Sun (Conradie, 2011), SA Climate Zones and Weather Files (Conradie, 2012) and Appropriate Passive Design Approaches for the Various Climatic Regions in South Africa (Conradie, 2013) detailed various aspects of the South African climatic characteristics that impacts directly on the design of comfortable and energy efficient buildings. The latter introduced some quantification of the appropriate passive strategies that is effective within the particular climatic regions. In said publications the new CSIR Köppen-Geiger map was introduced to support the study the South African climate. This map was used as a background climatic grouping method in a number of research projects to quantify appropriate passive methods to make structures within the different climatic regions more comfortable.

2. Classification of IBT systems

To quantify the performance of the various IBT systems a classification system has been developed for a set of representative IBT systems to facilitate performance investigations such as climate modelling and performance ranking. The technological composition of the building systems (Table 1) shows what distinguishes one building system from the next such as the superstructure and in some cases the superstructure finishes. A detailed analysis of the superstructure composition was therefore carried out for one typical representative system (indicated in light blue, Table 1) within each of the categories ranging from A to G and the results were then applied to the entire sub-group.

Table 1: Classification of Building Systems ranging from light to heavy weight

Classification Category	Agrement certified building system	Classification
Light Building System (LBS), steel structural frame	Amsa Building System Alternative Steel Building System FSM Building System Space Frame Building System Vela Building System	A
Light Building System (LBS), steel structural frame, insulated foundations	Imison 3 Building System Imison Stud Building System	B
Light building system (LBS), panels, light weight concrete	Cemforce GRC Building System Mi Panel Building System Goldflex 800 Building System Goldflex 100 Building System Goldflex 800 Seismic Building System	C
Hybrid Building System (HBS)	Automapolyblok Building System Aruba Building System Blast Building System Insulated Concrete Panel Building System Rapidwall Building System Styrox Building System	D
Heavy Weight Building System (HWBS), panels, dense concrete	Banbric Building System Robust Building System	E

Heavy Weight Building System (HWBS), building blocks	BESA 2 Building System Hydraform Building System Izoblok Building System	F
Masonry construction	Masonry without ceiling insulation	G

Due to the fact that social infrastructure such as schools normally do not have air conditioning and could be constructed in any of the twelve Köppen-Geiger climatic regions of South Africa, the use of appropriate building systems with compatible thermal performance becomes very important. To improve the internal thermal comfort further the application of the correct passive techniques would make the building more comfortable (Conradie, 2013). In the past both aspects were often sadly neglected and led to very uncomfortable infrastructure. For example if classrooms are overpopulated as well then it often becomes unbearably hot. When selecting a construction method for a particular region of South Africa, the thermal performance of the particular construction must be known and secondly what the most appropriate passive responses would be to make the building more comfortable. The latter has already been explored in previous chapters.

To address the first question, a calibrated thermal model of a typical classroom was developed in *Ecotect*™. A thorough calibration process compared the results of the thermal model with in-situ measured data to ensure accuracy.

The mass and other characteristics of the building envelope was used as a basis to group twenty three different IBT building systems into six basic building system classification types (A to F) that range from light to heavy weight building systems. The six classification types were thermally analysed in a cross section of 38 cities and towns that are representative of all the Köppen-Geiger climatic regions found in South Africa. The following Agrément Certified building systems were assumed to thermally represent five out of the six building system classification types:

- *Automapolyblok Building System*
- *Banbrick Building system*
- *Goldflex 800 Building System*
- *Imison 3 Building System*
- *BESA 2 Building System*

Over and above this list, a Light Steel Frame (LSF) construction, that is rapidly gaining acceptance, was modelled to thermally represent the remaining building system classification group. Finally, a base line construction method was also analyzed, that is, a traditional masonry construction that is currently predominant in South Africa (Category G). Three additional categories G1, D1 and E1 were added to represent insulated versions of Masonry, Automapolyblock and Banbrick respectively that have better thermal performance.

Table 2: Description of modelled building systems used to characterise systems in Table 1 above

Building system	Description	Ceiling	Classification
LSF[1]	Highly insulated	Insulated	**A**
Masonry	No insulation (No cavity wall as per DH Peta Secondary School)	Not insulated	**G**
Automapolyblock	Combination of thermal mass and insulation	Not insulated	**D**
Banbrick	Thermal mass	Not insulated	**E**
Goldflex 800	Combination of thermal mass and insulation	Insulated	**C**
Imison 3	Highly insulated, less thermal bridging	Insulated	**B**
BESA 2	High thermal mass (bitumen emulsion stabilised adobe blocks)	Insulated	**F**
Masonry	High thermal mass	Insulated	**G1**
Automapolyblock	Combination of thermal mass and insulation	Insulated	**D1**
Banbrick	Thermal mass	Insulated	**E1**

The amount of heating and cooling energy that will be required to maintain thermal comfort (20°C – 24°C as stipulated by SANS 204) in the different building systems was calculated. The detailed results are presented below for each Köppen-Geiger climatic region.

3. Köppen-Geiger classification

To facilitate grouping of the various systems within climatic regions the existing CSIR Köppen-Geiger map was used. The Köppen-Geiger climatic classification is internationally still the most well-known and widely

[1] The LSF construction is built as per SANS 517 standard and is representative of the classification category “LBS, steel structural frame” (Appendix C)

used general climatic map type. However it is recognized that the Köppen-Geiger map uses empirical functions based on temperature and precipitation and would not always accurately reflect the thermal comfort of a person within the particular climate. Thermal comfort is determined to a large extent by a combination of dry bulb temperature and relative humidity. At the moment the CSIR is creating new specialized maps based on for example Standard Effective Temperature (SET) to address abovementioned shortcoming.

In the interim the CSIR Köppen-Geiger map is still used to quantify the current South African climatic conditions accurately as illustrated in Figure 1 until the completion of newer specialized thermal comfort maps. The current Köppen map was created by the CSIR from 20 years of temperature and precipitation data (1985 – 2005) based on a 1 km x 1 km grid. The algorithms as described by Kottek (2006) were used to compile the map. This classification uses a concatenation of a maximum of three alphabetic characters that describe the main climatic category, amount of precipitation and temperature characteristics. (Table 3)

Table 3: Köppen-Geiger categories (Kottek, 2006)

Main climates		Precipitation		Temperature	
Symbol	**Description**	**Symbol**	**Description**	**Symbol**	**Description**
A	equatorial	W	desert	h	hot arid
B	arid	S	steppe	k	cold arid
C	warm temperate	f	fully humid	a	hot summer
D	snow	s	summer dry	b	warm summer
E	polar	w	winter dry	c	cool summer
		m	monsoonal	d	extremely continental
				F	polar frost
				T	polar tundra

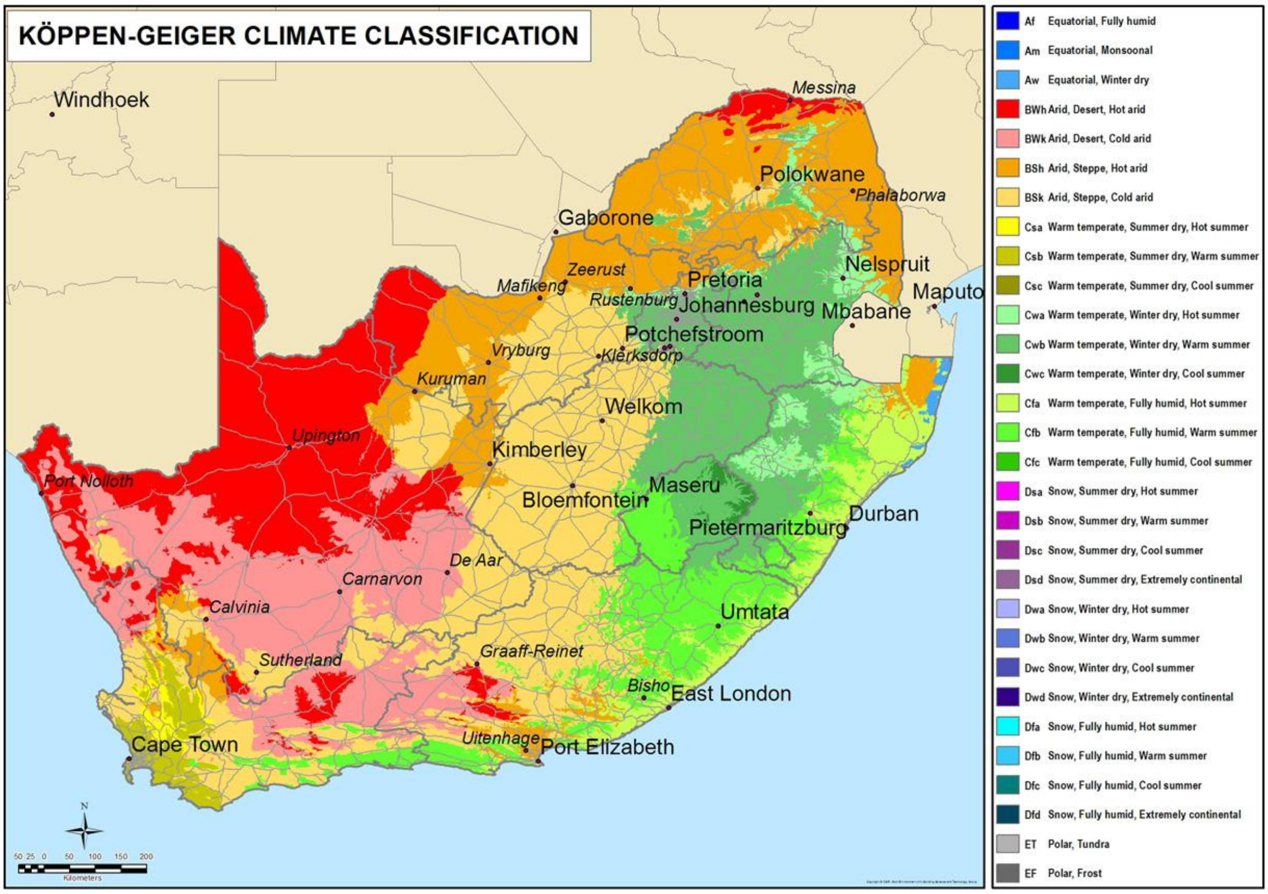


Figure 1: CSIR Köppen-Geiger map based on 1985 to 2005 Agricultural Research Council data on a fine 1 km x 1 km grid (Author)

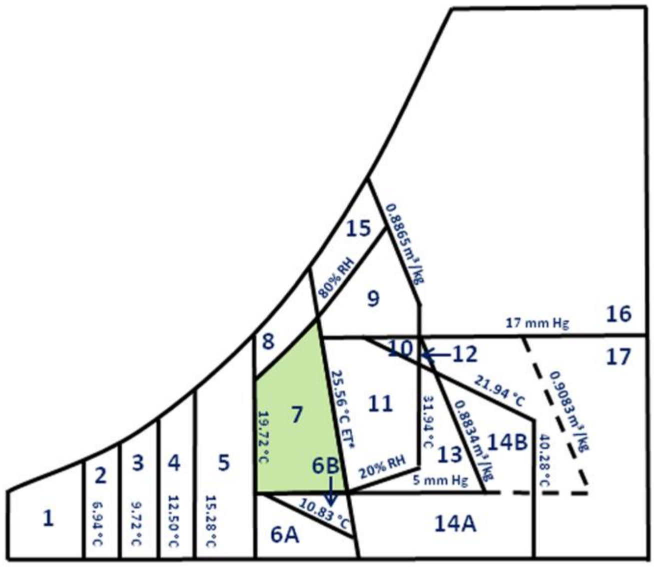
2 Effective strategies

One of the accessible methods that could be used to determine passive design strategies to make a given construction more comfortable is the bioclimatic chart that is today typically overlaid on the psychrometric chart. Bioclimatic design is used to define potential building design strategies that utilize natural energy resources and minimize energy use (Visitsak *et al*., 2004).

To address the problems of the original Olgyay (1963) chart, Givoni developed a chart for “envelop-dominated buildings” based on indoor conditions. In 1979, Milne and Givoni combined the different design strategies of the previous study of Givoni (1969) on the same chart. The Givoni-Milne bioclimatic chart is currently used by many architects. Software such as *Ecotect*™ has a psychometric chart with Givoni-Milne overlays. Figures 3 to 13 below illustrate the characteristics of the various climatic regions. This is the basis of determining which passive design strategies using the principles of the Givoni-Milne approach could be used to improve the comfort of buildings in the context of various different Köppen climatic regions in South Africa.

The weather files used in the analysis was generated by the Author using the *Meteonorm* software. The correlation between the weather file and the relevant Köppen climatic region was done by means of the high resolution CSIR developed Köppen map. The detailed performance tables below were created by means of exhaustive simulation of a typical classroom using *Ecotect*.

The set of tables below quantifies the performance of abovementioned IBT’s grouped by Köppen climatic region and analysed for 38 representative locations. In Figure 2 the green block indicates the comfort region as defined by Watson and labs. The ASHRAE Handbook of Fundamentals Comfort Model, 2005 was used previously to quantify appropriate passive measures to improve comfort. In this model it is assumed that people are dressed in normal winter clothes, Effective Temperatures of



Identification of climate control strategies on the Building Bioclimatic Chart (adapted after Givoni)

BIOCLIMATIC NEEDS ANALYSIS	
Total heating (< 19.72°C)	1-5
Total cooling (> 25.56 ET*)	9-17
Total comfort (19.72°C – 25.56°C ET*, 5 mm Hg – 80% RH)	7
Dehumidification (> 17 mm Hg or 80% RH)	8-9, 15-16
Humidification (< 5 mm Hg)	6A, 6B (14)
STRATEGIES OF CLIMATE CONTROL	
Restrict conduction	1-5; 9-11, 15-17
Restrict infiltration	1-5; 16-17
Promote solar gain	1-5
Restrict solar gain	6-17
Promote ventilation	9-11
Promote evaporative cooling	6B, 11, 13, 14A, 14B
Promote radiant cooling	10-13
Mechanical cooling	17
Mechanical cooling and dehumidification	15-16

Figure 2 Watson and Labs Building Bioclimatic Chart, based on the original Psychrometric chart based Bioclimatic Chart of Givoni.

20°C to 23.3°C measured at 50% relative humidity are applicable, which means the temperatures decrease slightly as humidity rises. The upper humidity limit is 17.8°C Wet Bulb and a lower Dew Point of 2.2°C. If people are dressed in light weight summer clothes then this comfort zone shifts 2.8°C warmer. Software Such as *Climate Consultant v5.4* developed by Robin Liggett and Murray Milne of the UCLA Energy Design Tools Group with technical support from Carlos Gomez and Don Leeper also supports the Adaptive Comfort Model of the ASHRAE standard 55-2004. However the latter do not provide quantified insights in the comprehensive set of strategies.

In tables 4 to 14 below the top part of the set estimates the amount of energy in kWh that would be required to achieve thermal comfort for a particular construction method. This consists of a Heating Load (H.L.), Cooling load (C.L.) and Total Load (T.L.) columns. The bottom part estimates the number of annual hours that the particular structure would be comfortable if no heating or cooling interventions are made. This consists Too Hot (T.H.), Too Cold (T.C.) and number of comfortable hours (Com). The best building system groups has been marked with light blue.

The following method was used to calculate rating for each system in the top table of each set. The average energy requirement was first calculated for the particular system in all the available locations. Then the minimum and maximum energy requirement was determined. Then the inverse of the average energy usage divided by the minimum energy usage multiplied by five created a score out of five. In other worlds, the less the total energy requirement, the better is the system. The best building system groups has been marked with light blue.

The following method was used to calculate the rating for the bottom table of each set. In this case the average number of comfort hours was first calculated for the particular system in all available locations. Then the minimum and maximum comfort hours of the set of averages were determined. The last step was to divide the average comfort hours for a particular system by the maximum average comfort hours multiplied by five to determine a performance score out of five.

To understand the numerous figures in the performance tables better and the characteristics of the particular climate a special overlay of the Watson and Labs psychrometric chart in Figure 2 and an annual climatic analysis of one representative location for that climatic region have been created. The darkness of the coloured blocks gives an indication of the amount of annual hours that the specific temperature/ humidity combination occurs. It is therefore a good indication of the fundamental characteristics such as hot, cold and humid. Over the years the comfort areas defined on the psychrometric chart changed quite a lot. In certain cases two areas were identified, one for summer and one for winter. The area indicated by blue is the comfort area as defined in the *Ecotect* software, whereas area 7 is the comfort area as defined by Watson and Labs.

2.1 Aw (Equatorial, Winter Dry)

This type of climate occurs currently in only 0.2% of the surface area of South Africa. Although it is currently a small area it is very likely to expand significantly with climate change over the next century. A tropical area such as Richards Bay that is close to Maputo analyzed below has a very humid climate. The most effective strategies are Sun Shading of Windows, Fan Forced Ventilation Cooling and Dehumidification. The best IBT's with regards energy requirement are class A, B, G1 and D1 and for comfort hours are G, C, F and G1. (Table 4)

Table 4: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification Aw (Author)

Köppen-Geiger climatic region	Aw				
Building system (kWh)	Class	Maputo			Rating
		H.L	C.L	T.L	
LSF	A	0	5636	5636	5.0
Masonry	G	0	9600	9600	2.9
Automapolyblock	D	0	9481	9481	3.0
Banbrick	E	1	11652	11654	2.4
Goldflex 800 seismic	C	0	6342	6342	4.4
Imison 3	B	0	5595	5595	5.0
BESA 2	F	0	6052	6052	4.6
Masonry with ceiling insulation	G1	0	5890	5890	4.8
Automapolyblock with ceiling insul.	D1	0	5815	5815	4.8
Banbrick with ceiling insulation	E1	0	7979	7979	3.5

Köppen-Geiger climatic region	Aw				
Building system (Hours)	Class	Maputo			Rating
		T.H	T.C	Com	
LSF	A	1923	2	187	1.5
Masonry	G	1579	2	531	4.3
Automapolyblock	D	1817	2	293	2.4
Banbrick	E	1672	2	438	3.6
Goldflex 800 seismic	C	1647	0	465	3.8
Imison 3	B	1942	2	168	1.4
BESA 2	F	1574	1	537	4.4
Masonry with ceiling insulation	G1	1500	0	612	5.0
Automapolyblock with ceiling insul.	D1	1800	1	311	2.5
Banbrick with ceiling insulation	E1	1642	1	469	3.8

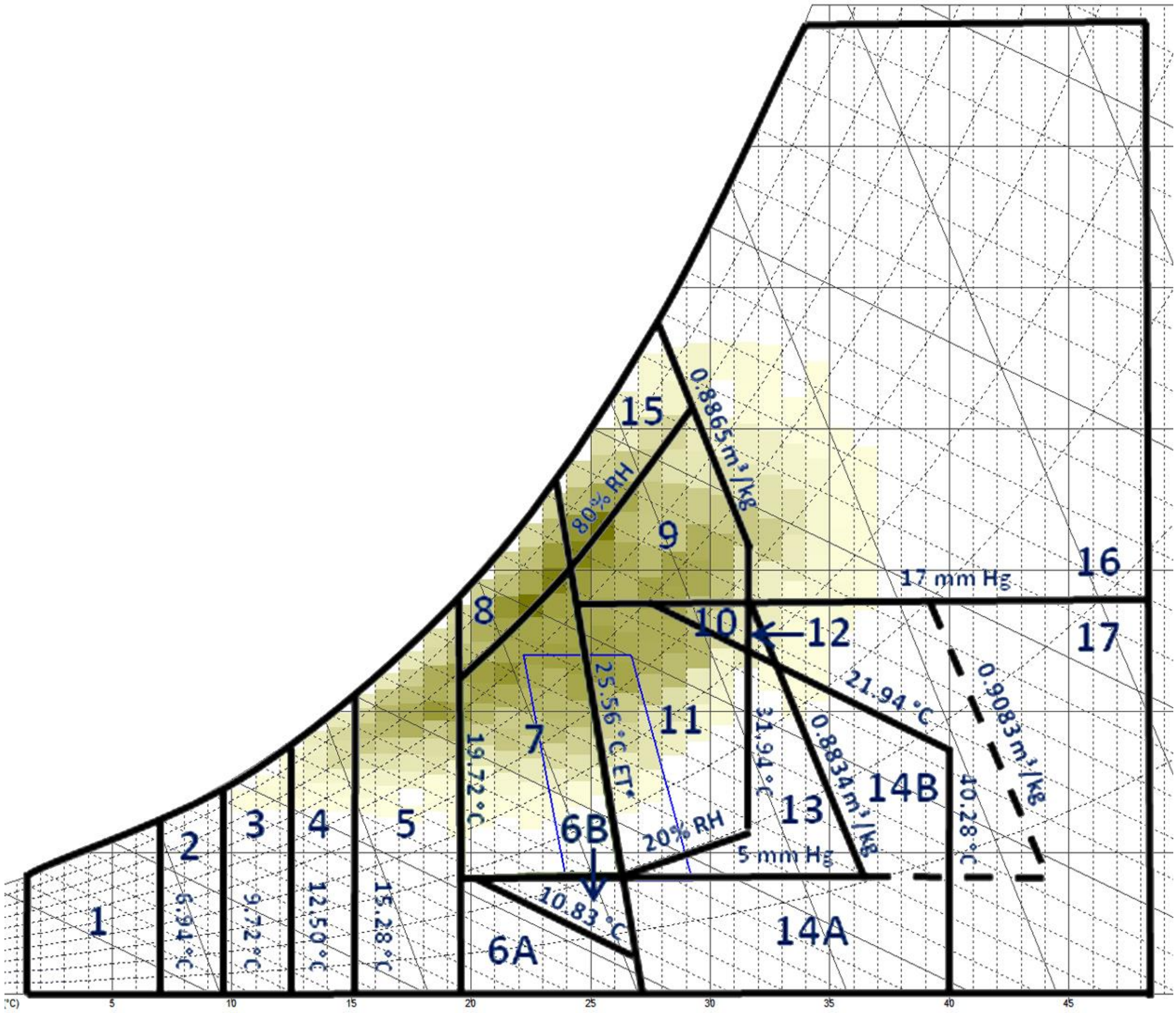


Figure 3: An overlay of the Maputo climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

2.2 Bsh (Arid Steppe, Hot Arid)

16.59% of the country's area falls within this category. If the other arid categories such as Bsk, Bwh and Bwk are included, 70.89% of the country's area has an arid climate. In this hot arid region Sun Shading of Windows, High Thermal Mass, Evaporative Cooling, Fan Forced Ventilation Cooling and Passive Heat Gain strategies are most beneficial. The best IBT's with regards energy requirement are class A, F, G1 and D1 and for comfort hours are G, C, G1 and D1. (Table 5)

Table 5: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification BSh (Author)

Köppen-Geiger climatic region	BSh																
Building system (kWh)	Class	Kimberley			Mmabatho Intl Airprt			Roodeplaat			Pietersburg			Port Elizabeth			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	146	3440	3586	30	3521	3551	9	3655	3665	19	2994	3013	9	2727	2735	4.1
Masonry	G	804	5633	6437	384	5932	6316	244	5756	6000	355	4535	4890	315	3244	3559	2.5
Automapolyblock	D	440	6456	6896	180	6890	7070	97	6804	6901	155	5646	5801	111	4668	4779	2.2
Banbrick	E	1257	7090	8347	705	7439	8144	501	7407	7908	674	5726	6400	627	4413	5041	1.9
Goldflex 800 seismic	C	203	3599	3803	55	3713	3769	24	3750	3775	40	2995	3036	31	2378	2409	4.1
Imison 3	B	92	3667	3758	15	3745	3759	5	3907	3912	8	3248	3256	3	3053	3056	3.8
BESA 2	F	425	3099	3524	169	3161	3330	84	3141	3226	147	2393	2540	105	1733	1838	4.7
Masonry with ceiling insulation	G1	427	2965	3393	180	2980	3160	92	2954	3046	157	2199	2356	109	1558	1666	5.0
Automapolyblock with ceiling insul.	D1	129	3526	3655	27	3608	3635	9	3686	3695	17	3016	3033	13	2629	2642	4.1
Banbrick with ceiling insulation	E1	860	4268	5129	468	4287	4755	317	4329	4646	450	3242	3691	379	2414	2793	3.2

Köppen-Geiger climatic region	BSh																
Building system (Hours)	Class	Kimberley			Mmabatho Intl Airprt			Roodeplaat			Pietersburg			Port Elizabeth			Rating
		T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	
LSF	A	1097	307	708	1140	147	825	1210	75	827	942	135	1035	659	165	1288	4.1
Masonry	G	834	541	737	829	383	900	840	267	1005	604	388	1120	283	362	1467	4.6
Automapolyblock	D	1010	394	708	1079	250	783	1118	158	836	868	223	1021	546	221	1345	4.1
Banbrick	E	900	553	659	935	387	790	965	304	843	721	420	971	417	414	1281	4.0
Goldflex 800 seismic	C	877	453	782	865	282	965	851	158	1103	597	262	1253	278	223	1611	5.0
Imison 3	B	1091	282	739	1146	122	844	1204	71	837	937	113	1062	625	165	1322	4.2
BESA 2	F	845	543	724	836	394	882	827	236	1049	586	387	1139	266	294	1552	4.7
Masonry with ceiling insulation	G1	799	565	748	766	426	920	738	251	1123	490	419	1203	199	326	1587	4.9
Automapolyblock with ceiling insul.	D1	959	375	778	982	186	944	1015	94	1003	756	159	1197	392	184	1536	4.8
Banbrick with ceiling insulation	E1	856	555	701	856	386	870	870	288	954	626	419	1067	330	368	1414	4.4

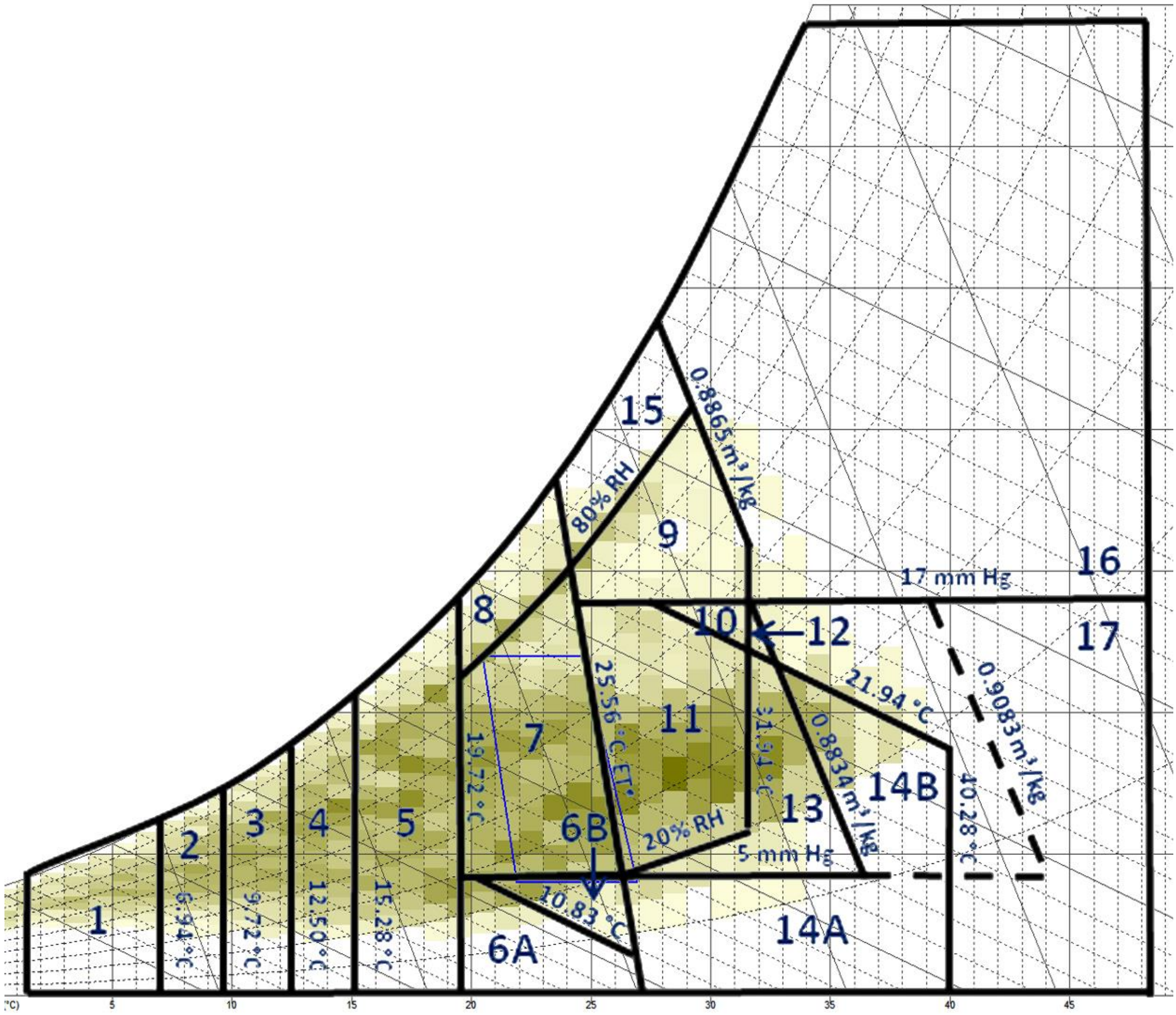


Figure 4: An overlay of the Kimberley climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

2.3 Bsk (Arid Steppe, Cold Arid)

This is currently the largest arid climate type in South Africa with 23.81% of the surface area. Shading in the summer and heat gain in winter is important because it gets very cold in winter. Being an arid region evaporative cooling is also efficient in some areas indicated below. The best IBT's with regards energy requirement are class A, C, F, G1 and D1 and for comfort hours are G, C, B, F, G1 and D1. (Table 6)

Table 6: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification BSk (Author)

Köppen-Geiger climatic region	BSk																						
Building system (kWh)	Class	Aliwal North			Bloemfontein			Calvinia			Langebaanweg SAAF			Middelburg Cape			Mossel Bay			Welkom			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	223	2433	2656	267	2515	2781	268	2688	2957	55	2570	2624	289	2222	2512	3	2764	2767	34	3702	3736	4.3
Masonry	G	1151	3786	4937	1242	4086	5329	1203	4247	5450	619	3515	4135	1248	3470	4718	298	3106	3404	456	6130	6587	2.5
Automapolyblock	D	644	5067	5711	697	5093	5790	699	5203	5901	318	4623	4941	695	4565	5259	96	4525	4621	215	7097	7312	2.2
Banbrick	E	1728	5005	6733	1824	5199	7023	1819	5439	7258	1098	4478	5576	1778	4503	6281	605	4171	4776	842	7816	8658	1.9
Goldflex 800 seismic	C	311	2429	2740	354	2602	2956	357	2729	3086	106	2449	2554	365	2199	2564	27	2391	2418	67	3918	3986	4.2
Imison 3	B	140	2697	2838	168	2738	2906	179	2914	3092	26	2838	2863	176	2460	2637	1	3083	3084	19	3950	3968	4.0
BESA 2	F	668	1924	2592	752	2064	2815	701	2193	2895	265	1858	2123	754	1738	2492	101	1683	1784	195	3298	3493	4.7
Masonry with ceiling insulation	G1	677	1777	2453	754	1927	2681	690	2086	2777	265	1708	1973	754	1608	2362	102	1514	1616	208	3110	3317	5.0
Automapolyblock with ceiling insul.	D1	199	2465	2665	234	2564	2798	242	2735	2977	53	2561	2614	249	2256	2506	8	2689	2697	31	3818	3849	4.3
Banbrick with ceiling insulation	E1	1225	2628	3854	1304	2799	4103	1261	3070	4331	683	2481	3164	1254	2379	3633	361	2358	2719	559	4639	5198	3.2

Köppen-Geiger climatic region	BSk																						
Building system (Hours)	Class	Aliwal North			Bloemfontein			Calvinia			Langebaanweg SAAF			Middelburg Cape			Mossel Bay			Welkom			Rating
		T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	C	T.H	T.C	Com	
LSF	A	857	472	783	901	528	683	885	476	751	737	285	1090	751	517	844	702	200	1210	1204	192	716	4.4
Masonry	G	543	775	794	596	805	711	598	763	751	433	582	1097	483	866	763	311	350	1451	890	406	816	4.6
Automapolyblock	D	760	557	795	799	583	730	802	554	756	667	380	1065	652	622	838	591	251	1270	1125	274	713	4.4
Banbrick	E	644	725	743	693	760	659	684	752	676	519	610	983	563	811	738	438	406	1268	985	418	709	4.1
Goldflex 800 seismic	C	563	691	858	612	726	774	621	661	830	446	405	1261	497	764	851	314	248	1550	943	308	861	5.0
Imison 3	B	834	416	862	880	461	771	878	435	799	729	265	1118	737	462	913	684	197	1231	1206	159	747	4.6
BESA 2	F	554	787	771	613	816	683	605	757	750	426	540	1146	489	861	762	295	303	1514	913	409	790	4.6
Masonry with ceiling insulation	G1	474	822	816	532	850	730	546	786	780	359	567	1186	418	905	789	240	317	1555	830	437	845	4.8
Automapolyblock with ceiling insul.	D1	675	572	865	722	616	774	724	536	852	559	310	1243	582	611	919	445	215	1452	1047	227	838	5.0
Banbrick with ceiling insulation	E1	597	761	754	645	791	676	627	772	713	454	591	1067	508	849	755	349	375	1388	922	416	774	4.4

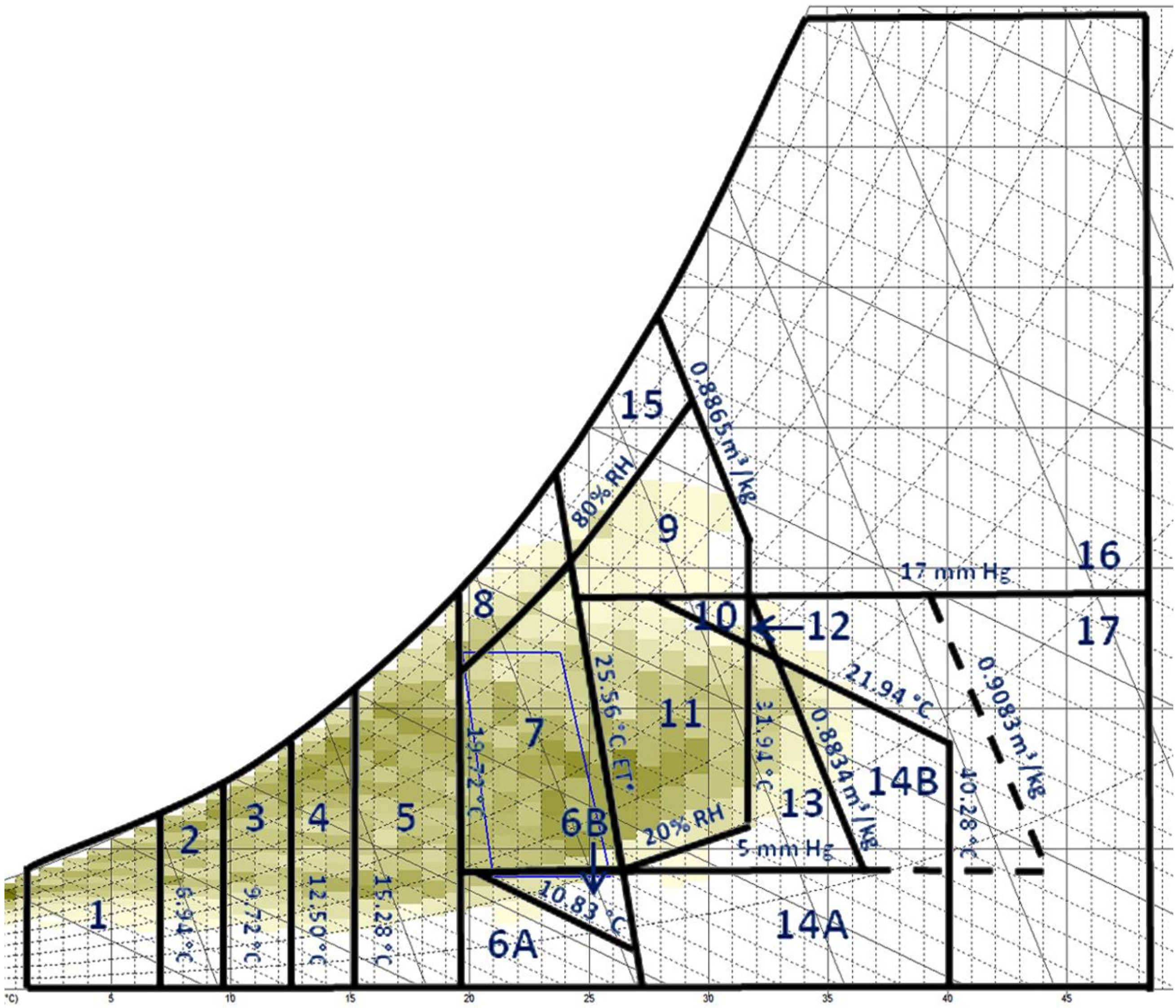


Figure 5: An overlay of the Bloemfontein climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

2.4 Bwh (Arid, Desert, Hot Arid)

This climate type occurs in 16.29% of the surface area and is an extremely harsh climate. Sun Shading of Windows, High Thermal Mass, Evaporative Cooling and heat gain strategies in winter is beneficial. Alexander Bay is an anomaly due to the fact that it is close to the sea and the very cold Benguela sea current that change the climatic characteristics. The best IBT's with regards energy requirement are class A, F, G1 and D1 and for comfort hours are G, F, G1 and D1. (Table 7)

Table 7: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification Bwh (Author)

Köppen-Geiger climatic region	Bwh										
Building system (kWh)	Class	Alexander Bay			Beitbridge			Upington			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	151	2201	2352	0	6259	6259	78	4456	4533	4.7
Masonry	G	785	2978	3764	9	10527	10536	556	7660	8216	2.8
Automapolyblock	D	398	4069	4467	0	10653	10653	304	8225	8529	2.6
Banbrick	E	1285	3853	5138	49	13128	13177	940	9505	10445	2.2
Goldflex 800 seismic	C	217	2028	2245	0	6910	6910	126	4777	4903	4.4
Imison 3	B	85	2426	2511	0	6297	6297	44	4601	4645	4.6
BESA 2	F	485	1486	1971	0	6403	6403	275	4315	4590	4.8
Masonry with ceiling insulation	G1	473	1351	1824	0	6206	6206	279	4171	4450	5.0
Automapolyblock with ceiling insul.	D1	137	2174	2311	0	6464	6464	73	4549	4622	4.7
Banbrick with ceiling insulation	E1	908	2093	3001	19	8857	8875	620	5840	6460	3.4

Köppen-Geiger climatic region	Bwh										
Building system (Hours)	Class	Alexander Bay			Beitbridge			Upington			Rating
		T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	
LSF	A	639	499	974	1915	21	176	1301	208	603	3.9
Masonry	G	351	740	1021	1642	27	443	1081	419	612	4.6
Automapolyblock	D	555	559	998	1857	24	231	1249	290	573	4.0
Banbrick	E	438	752	922	1732	42	338	1129	415	568	4.1
Goldflex 800 seismic	C	363	613	1136	1672	14	426	1122	322	668	5.0
Imison 3	B	628	482	1002	1932	18	162	1309	185	618	4.0
BESA 2	F	353	728	1031	1605	18	489	1090	408	614	4.8
Masonry with ceiling insulation	G1	280	752	1080	1565	16	531	1050	428	634	5.0
Automapolyblock with ceiling insul.	D1	465	546	1101	1783	18	311	1198	257	657	4.6
Banbrick with ceiling insulation	E1	381	754	977	1675	23	414	1090	416	606	4.4

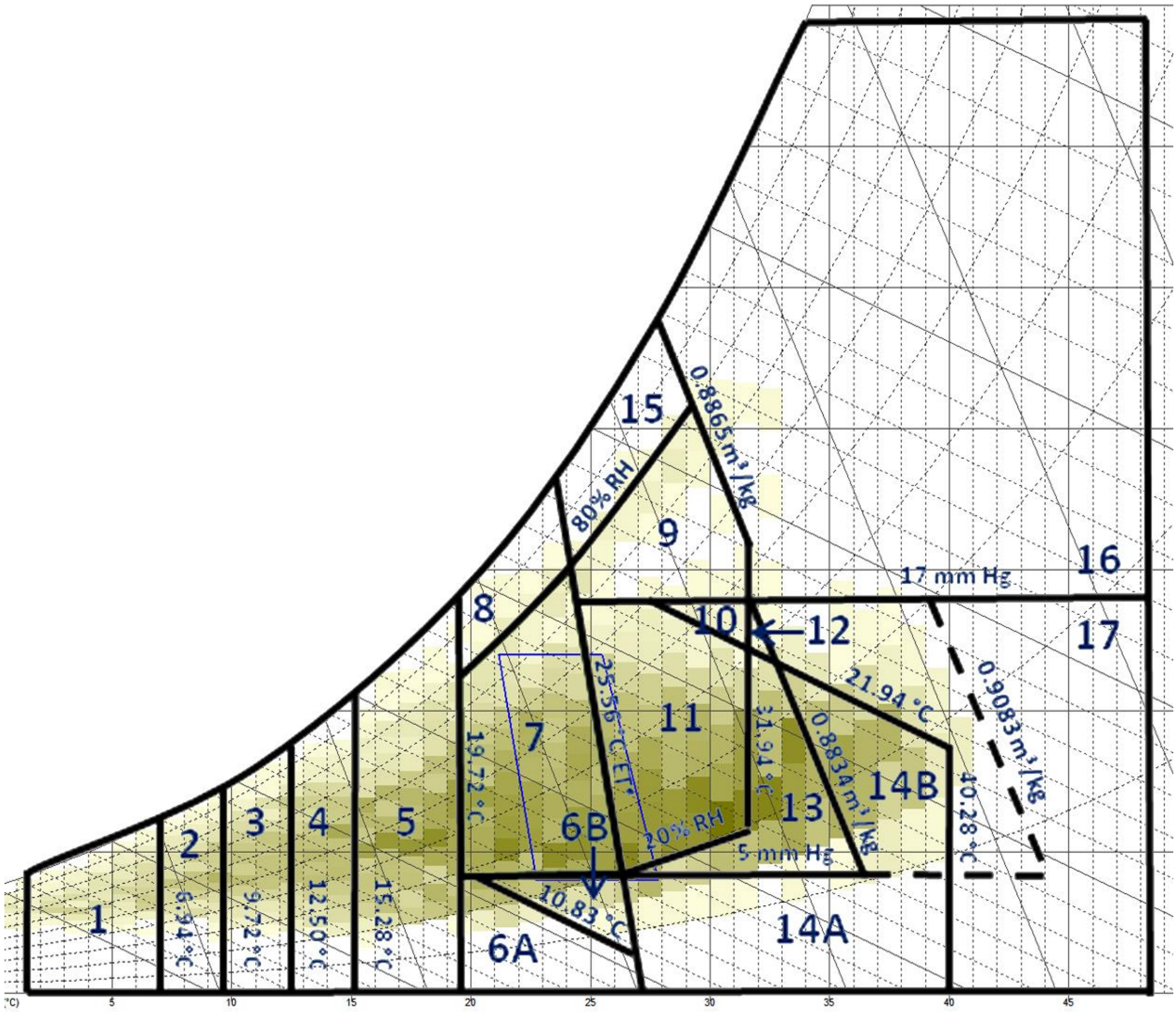


Figure 6: An overlay of the Upington climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

2.5 Bwk (Arid, Desert, Cold Arid)

This climate type occurs in 14.2% of the surface area and is also extremely harsh with cold winters. The most beneficial strategies are Sun Shading of Windows, Evaporative Cooling and Heat Gain in winter. The best IBT's with regards energy requirement are class A, F, G1 and D1 and for comfort hours are A, D, C, B and D1. (Table 8)

Table 8: Quantified strategies for Köppen climatic classification Bwk (Author)

Köppen-Geiger climatic region	Bwk							
Building system (kWh)	Class	De Aar			Springbok			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	179	3109	3287	180	2899	3079	4.7
Masonry	G	903	5145	6048	801	4566	5368	2.6
Automapolyblock	D	497	5958	6455	452	5430	5881	2.4
Banbrick	E	1349	6435	7784	1219	5703	6922	2.0
Goldflex 800 seismic	C	236	3231	3467	243	2980	3223	4.5
Imison 3	B	106	3294	3400	111	3065	3177	4.6
BESA 2	F	509	2782	3291	482	2469	2950	4.8
Masonry with ceiling insulation	G1	509	2661	3170	473	2348	2821	5.0
Automapolyblock with ceiling insul.	D1	153	3160	3312	162	2912	3074	4.7
Banbrick with ceiling insulation	E1	920	3782	4702	829	3297	4126	3.4

Köppen-Geiger climatic region	Bwk							
Building system (Hours)	Class	De Aar			Springbok			Rating
		T.H	T.C	Com	T.H	T.C	Com	
LSF	A	980	369	763	831	391	890	4.6
Masonry	G	743	652	717	594	642	876	4.4
Automapolyblock	D	902	448	762	762	453	897	4.6
Banbrick	E	809	632	671	650	636	826	4.1
Goldflex 800 seismic	C	778	556	778	615	527	970	4.8
Imison 3	B	978	325	809	831	365	916	4.8
BESA 2	F	757	659	696	596	633	883	4.4
Masonry with ceiling insulation	G1	702	694	716	552	661	899	4.5
Automapolyblock with ceiling insul.	D1	862	431	819	682	445	985	5.0
Banbrick with ceiling insulation	E1	777	644	691	619	636	857	4.3

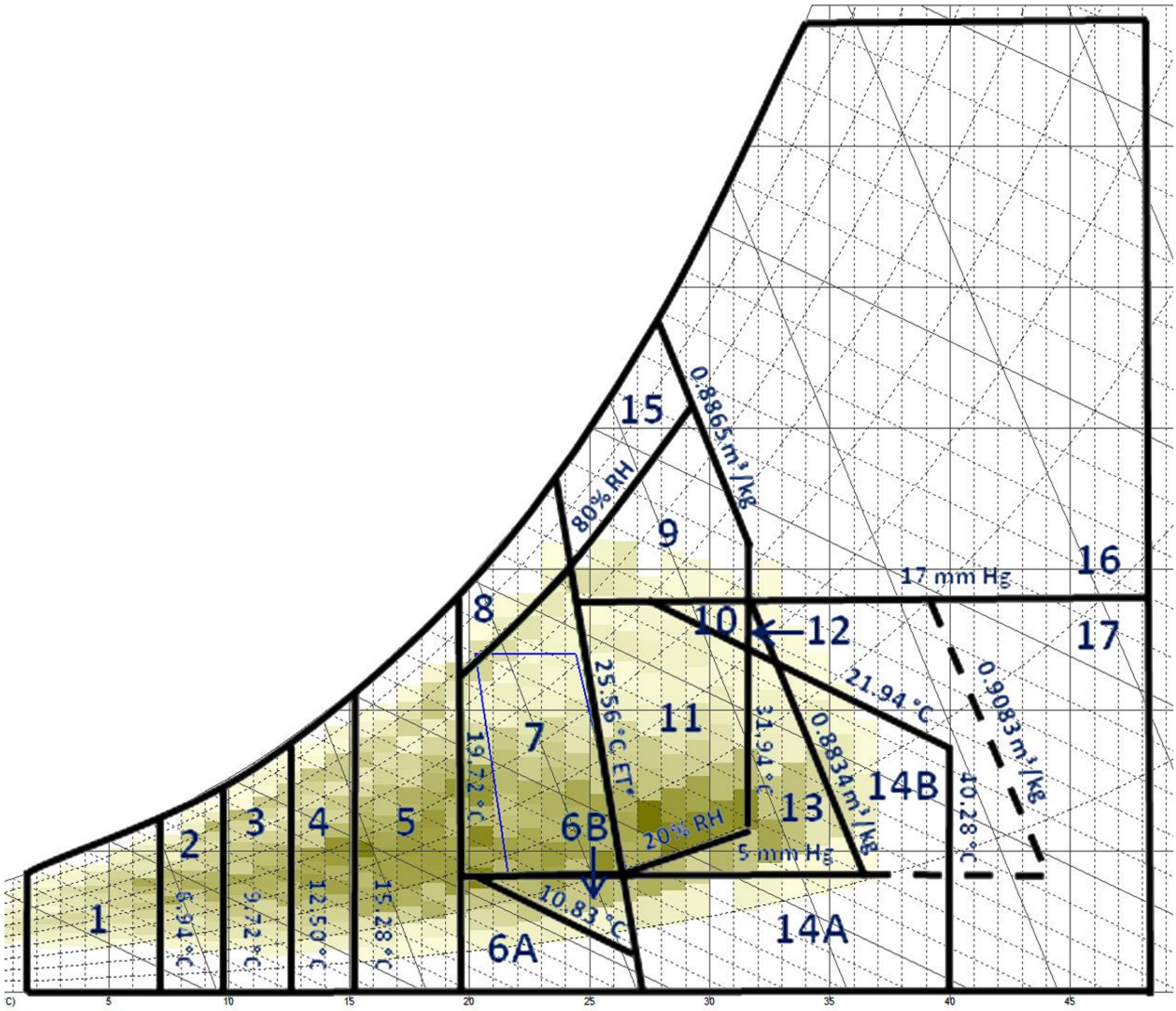


Figure 7: An overlay of the De Aar climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

2.6 Cfa (Warm temperate, Fully Humid, Hot Summer)

This climatic region, only 3.7% of the surface area, is part of the warm temperate family of climates in South Africa that consists of Cfa, Cfb, Cfc, Csa, Csb, Cwa, Cwb and Cwc. Strategies that are beneficial in these high humidity areas are inter alia Sun Shading of Windows, Fan Forced Ventilation Cooling and Heat Gains in winter. Dehumidification is also beneficial. The best IBT's with regards energy requirement are class C, F, G1 and D1 and for comfort hours are G, C, F and G1. (Table 9)

Table 9: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification Cfa (Author)

Köppen-Geiger climatic region	Cfa										
Building system (kWh)	Class	Cape St Francis			Durban			East London			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	4	2654	2657	0	4152	4152	1	3070	3071	3.3
Masonry	G	260	2832	3093	29	5862	5891	160	3708	3868	2.6
Automapolyblock	D	73	4426	4499	2	6538	6540	39	5071	5110	2.0
Banbrick	E	563	3994	4557	114	7410	7524	354	5020	5374	1.9
Goldflex 800 seismic	C	20	2168	2188	0	4269	4269	8	2766	2774	3.6
Imison 3	B	1	3017	3018	0	4303	4303	0	3386	3386	3.1
BESA 2	F	81	1400	1482	3	3604	3607	40	2093	2133	4.6
Masonry with ceiling insulation	G1	86	1199	1284	3	3418	3421	44	1869	1913	5.0
Automapolyblock with ceiling insul.	D1	6	2576	2582	0	4225	4225	2	3046	3047	3.4
Banbrick with ceiling insulation	E1	332	2051	2383	50	4901	4951	206	2928	3134	3.2

Köppen-Geiger climatic region	Cfa										
Building system (Hours)	Class	Cape St Francis			Durban			East London			Rating
		T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	
LSF	A	593	196	1323	1251	40	821	775	124	1213	3.5
Masonry	G	188	346	1578	793	56	1263	372	232	1508	4.6
Automapolyblock	D	487	248	1377	1109	44	959	673	161	1278	3.8
Banbrick	E	354	399	1359	928	90	1094	529	284	1299	4.0
Goldflex 800 seismic	C	164	235	1713	814	33	1265	365	153	1594	4.8
Imison 3	B	562	195	1355	1250	37	825	773	120	1219	3.6
BESA 2	F	167	283	1662	758	39	1315	351	194	1567	4.8
Masonry with ceiling insulation	G1	104	297	1711	681	32	1399	277	203	1632	5.0
Automapolyblock with ceiling insul.	D1	283	206	1623	987	33	1092	502	132	1478	4.4
Banbrick with ceiling insulation	E1	237	358	1517	839	67	1206	412	234	1466	4.4

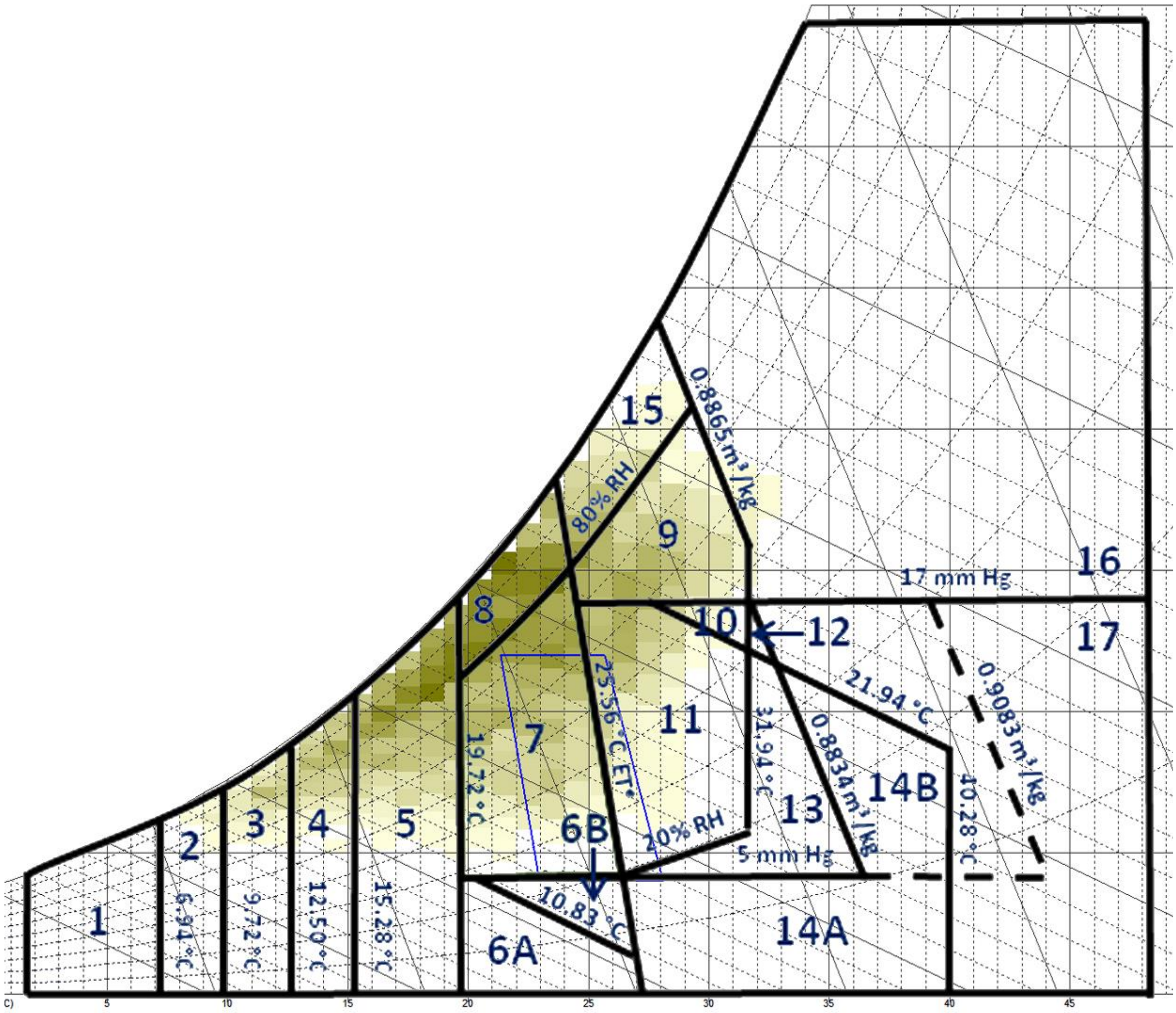


Figure 8: An overlay of the Durban climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

2.7 Cfb (Warm temperate, Fully humid, Warm summer)

8.06% of the surface area falls in this category. Beneficial strategies are Sun Shading of Windows and heat gains in winter. Fan Forced Ventilation Cooling still works, but is not as beneficial as with Cfa. The best IBT's with regards energy requirement are class C, F, G1 and D1 and for comfort hours are C, F, G1 and D1. (Table 10)

Table 10: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification Cfb (Author)

Köppen-Geiger climatic region	Cfb							
Building system (kWh)	Class	George PW Botha			Umtata			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	75	1921	1996	22	3180	3202	3.4
Masonry	G	682	1984	2666	371	4542	4913	2.4
Automapolyblock	D	342	3402	3744	168	5716	5884	1.9
Banbrick	E	1145	2805	3950	707	6045	6752	1.7
Goldflex 800 seismic	C	134	1523	1658	49	3085	3134	3.7
Imison 3	B	37	2217	2254	11	3482	3492	3.1
BESA 2	F	332	957	1288	150	2497	2648	4.5
Masonry with ceiling insulation	G1	334	799	1133	159	2288	2447	5.0
Automapolyblock with ceiling insul.	D1	76	1831	1907	21	3161	3182	3.5
Banbrick with ceiling insulation	E1	760	1301	2061	452	3613	4065	2.9

Köppen-Geiger climatic region	Cfb							
Building system (Hours)	Class	George PW Botha			Umtata			Rating
		T.H	T.C	Com	T.H	T.C	Com	
LSF	A	418	335	1359	1010	165	937	4.3
Masonry	G	135	694	1283	644	389	1079	4.5
Automapolyblock	D	347	454	1311	914	252	946	4.3
Banbrick	E	237	706	1169	774	396	942	4.0
Goldflex 800 seismic	C	128	508	1476	669	272	1171	5.0
Imison 3	B	397	323	1392	995	156	961	4.4
BESA 2	F	123	653	1336	653	373	1086	4.6
Masonry with ceiling insulation	G1	78	699	1335	561	414	1137	4.7
Automapolyblock with ceiling insul.	D1	209	395	1508	797	201	1114	5.0
Banbrick with ceiling insulation	E1	159	687	1266	703	389	1020	4.3

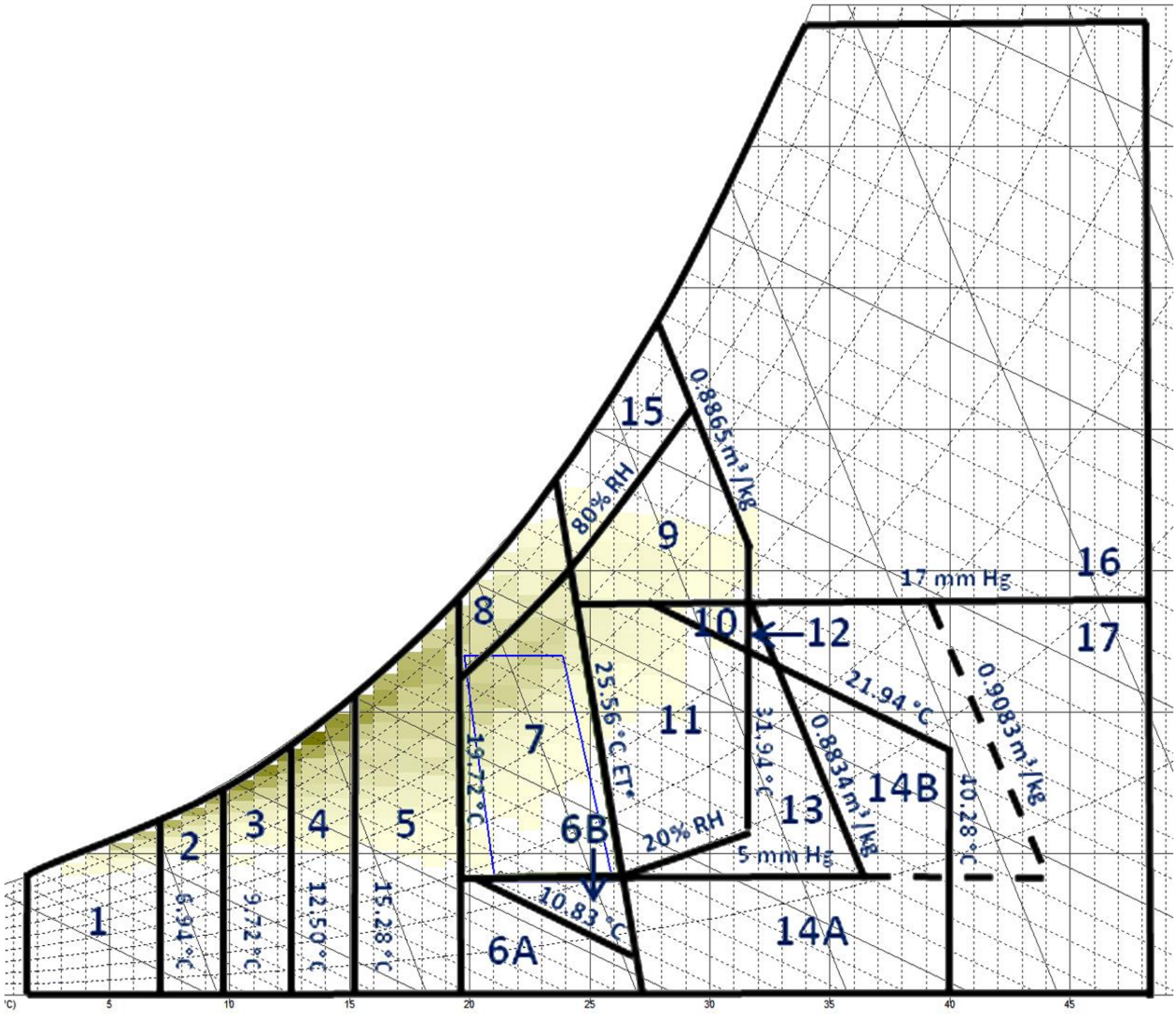


Figure 9: An overlay of the George climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

2.8 Csa (Warm temperate, summer dry, Hot summer)

This is a rather problematic winter rainfall region that covers only 0.44% of the surface area in the Western Cape Swartland area. The only strategies that can be considered here from a passive point of view are Sun Shading of Windows and heat gains in winter. Fan Forced Ventilation Cooling contributes surprisingly little. The best IBT's with regards energy requirement are class C, F, G1 and D1 and for comfort hours are G, C, G1 and D1. (Table 11)

Table 11: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification Csa (Author)

Köppen-Geiger climatic region	Csa							
Building system (kWh)	Class	Riebeeck Wes			Wellington			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	34	2415	2448	39	2393	2432	3.4
Masonry	G	523	3054	3577	534	3069	3603	2.3
Automapolyblock	D	245	4281	4526	246	4253	4499	1.8
Banbrick	E	954	3886	4840	970	3925	4894	1.7
Goldflex 800 seismic	C	82	2147	2229	82	2152	2234	3.7
Imison 3	B	16	2700	2716	17	2668	2685	3.1
BESA 2	F	213	1579	1792	219	1588	1806	4.6
Masonry with ceiling insulation	G1	213	1445	1658	218	1461	1680	5.0
Automapolyblock with ceiling insul.	D1	35	2317	2352	37	2342	2378	3.5
Banbrick with ceiling insulation	E1	588	2123	2711	603	2115	2718	3.1

Köppen-Geiger climatic region	Csa							
Building system (Hours)	Class	Riebeeck Wes			Wellington			Rating
		T.H	T.C	Com	T.H	T.C	Com	
LSF	A	625	254	1233	623	261	1228	4.3
Masonry	G	331	514	1267	316	532	1264	4.4
Automapolyblock	D	542	338	1232	538	334	1240	4.3
Banbrick	E	434	575	1103	437	594	1081	3.8
Goldflex 800 seismic	C	322	347	1443	316	352	1444	5.0
Imison 3	B	614	251	1247	610	257	1245	4.3
BESA 2	F	310	462	1340	307	472	1333	4.6
Masonry with ceiling insulation	G1	251	497	1364	245	505	1362	4.7
Automapolyblock with ceiling insul.	D1	438	284	1390	420	283	1409	4.8
Banbrick with ceiling insulation	E1	337	547	1228	337	568	1207	4.2

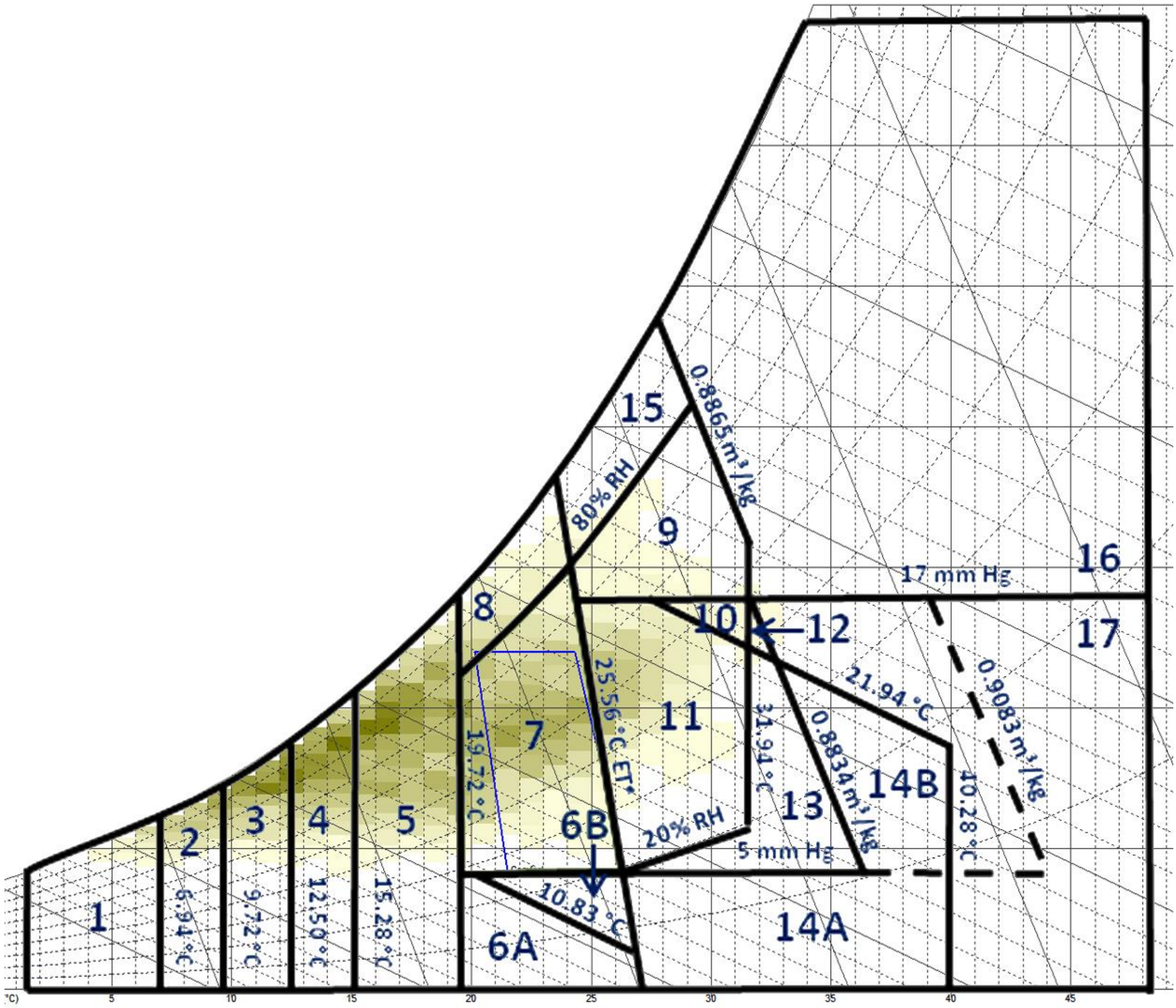


Figure 10: An overlay of the Wellington climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

2.9 Csb (Warm temperate, Fully humid, Warm summer)

This climate is a winter rainfall area that covers 1.59% of the surface area in the vicinity of Cape Town. Beneficial strategies are Sun Shading of Windows and heat gains in winter. Evaporative Cooling is not efficient at all. The best IBT's with regards energy requirement are class A, F, G1 and D1 and for comfort hours are C, B, F, G1 and D1. (Table 12)

Table 12: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification Csb (Author)

Köppen-Geiger climatic region	Csb							
Building system (kWh)	Class	Cape Town			Stellenbosch			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	99	2032	2131	42	2432	2473	3.5
Masonry	G	801	2627	3428	546	3117	3663	2.3
Automapolyblock	D	427	3721	4147	264	4357	4621	1.9
Banbrick	E	1321	3314	4635	982	4072	5054	1.7
Goldflex 800 seismic	C	177	1819	1995	87	2205	2291	3.8
Imison 3	B	51	2310	2361	19	2721	2740	3.2
BESA 2	F	395	1299	1694	224	1603	1827	4.6
Masonry with ceiling insulation	G1	390	1180	1570	222	1466	1688	5.0
Automapolyblock with ceiling insul.	D1	100	1966	2066	41	2373	2414	3.6
Banbrick with ceiling insulation	E1	866	1684	2549	606	2187	2793	3.0

Köppen-Geiger climatic region	Csb							
Building system (Hours)	Class	Cape Town			Stellenbosch			Rating
		T.H	T.C	Com	T.H	T.C	Com	
LSF	A	512	325	1275	637	257	1218	4.4
Masonry	G	251	683	1178	323	539	1250	4.3
Automapolyblock	D	435	443	1234	549	334	1229	4.4
Banbrick	E	341	737	1034	444	587	1081	3.8
Goldflex 800 seismic	C	243	499	1370	321	352	1439	5.0
Imison 3	B	494	314	1304	624	254	1234	4.5
BESA 2	F	239	679	1194	312	483	1317	4.5
Masonry with ceiling insulation	G1	180	719	1213	256	511	1345	4.5
Automapolyblock with ceiling insul.	D1	326	368	1418	429	287	1396	5.0
Banbrick with ceiling insulation	E1	266	699	1147	352	551	1209	4.2

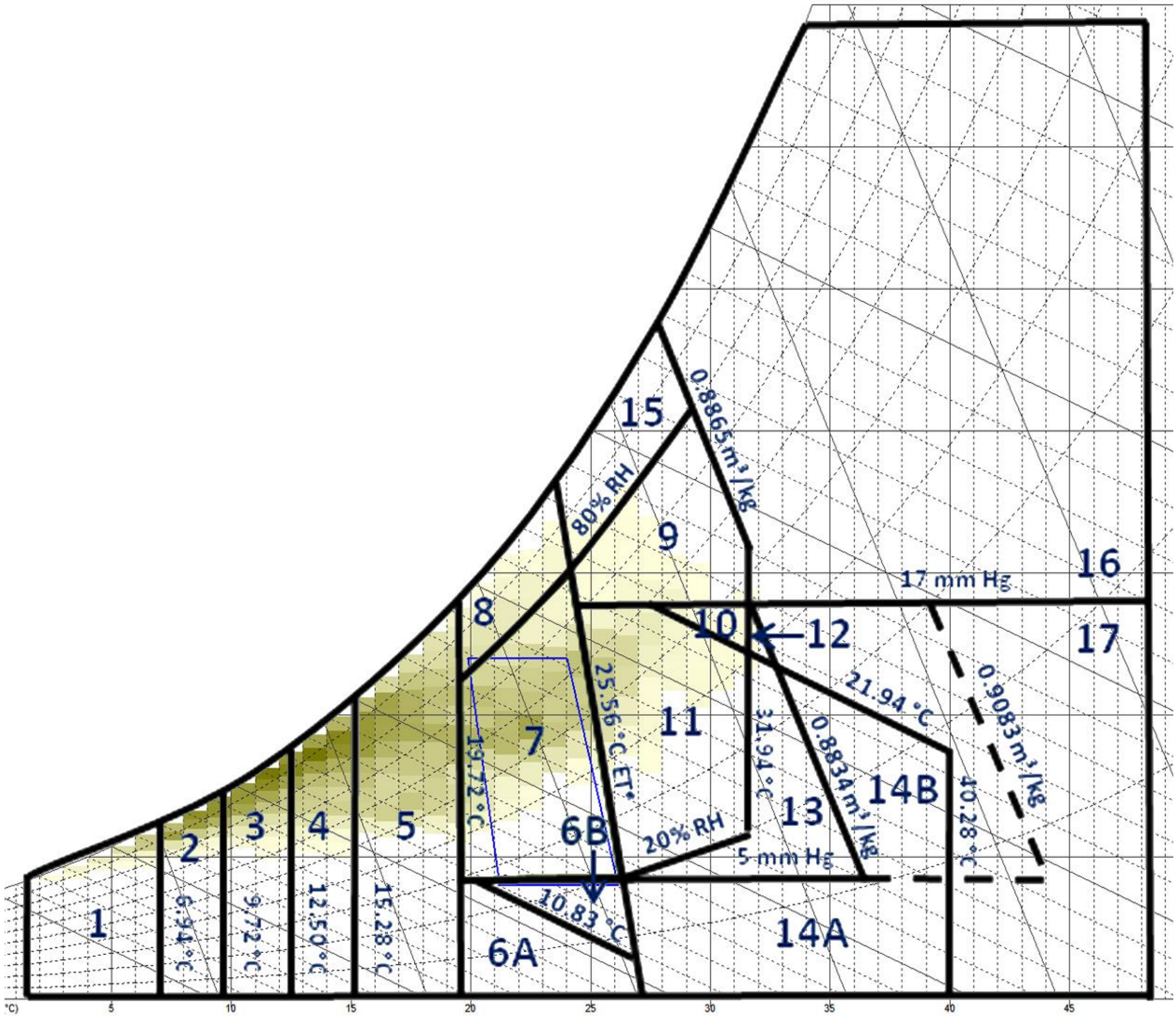


Figure 11: An overlay of the Cape Town climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

3.0 Cwa (Warm temperate, Winter dry, Hot summer)

This climatic region covers 2.69% of the surface area and includes the central part of Pretoria. Recommended strategies are Sun Shading of Windows, Fan Forced Ventilation Cooling and heat gains in winter. The best IBT's with regards energy requirement are class A, F, G1 and D1 and for comfort hours are G, C, F, G1 and D1. (Table 13)

Table 13: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification Cwa (Author)

Köppen-Geiger climatic region	Cwa													
Building system (kWh)	Class	Manzini Matsapa			Nelspruit			Pretoria Berea			Pretoria Forum			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	0	4990	4990	0	4769	4769	1	3739	3740	25	3188	3213	4.4
Masonry	G	11	8063	8074	31	7497	7528	150	5856	6006	367	4863	5230	2.7
Automapolyblock	D	1	8480	8481	4	8080	8084	55	6902	6957	174	5972	6146	2.5
Banbrick	E	45	10098	10143	120	9393	9513	382	7589	7971	682	6181	6862	2.1
Goldflex 800 seismic	C	0	5424	5424	0	5046	5046	3	3816	3819	51	3179	3230	4.2
Imison 3	B	0	5080	5080	0	4895	4895	0	3968	3969	12	3418	3430	4.2
BESA 2	F	0	4854	4854	4	4477	4481	26	3208	3233	156	2578	2733	4.8
Masonry with ceiling insulation	G1	0	4688	4688	4	4274	4279	30	3103	3133	163	2416	2579	5.0
Automapolyblock with ceiling insul.	D1	0	5146	5146	0	4875	4875	1	3733	3734	23	3194	3217	4.3
Banbrick with ceiling insulation	E1	20	6657	6677	57	6101	6157	219	4459	4678	451	3470	3921	3.4

Köppen-Geiger climatic region	Cwa													
Building system (Hours)	Class	Manzini Matsapa			Nelspruit			Pretoria Berea			Pretoria Forum			Rating
		T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	
LSF	A	1689	26	397	1536	40	536	1365	59	688	1004	130	978	3.2
Masonry	G	1285	33	794	1180	77	855	915	215	982	661	383	1068	4.5
Automapolyblock	D	1568	29	515	1448	47	617	1267	91	754	927	229	956	3.5
Banbrick	E	1380	49	683	1284	93	735	1000	253	859	780	401	931	3.9
Goldflex 800 seismic	C	1355	22	735	1222	41	849	981	90	1041	679	252	1181	4.6
Imison 3	B	1702	24	386	1546	35	531	1403	55	654	988	109	1015	3.2
BESA 2	F	1247	28	837	1157	56	899	912	171	1029	661	373	1078	4.7
Masonry with ceiling insulation	G1	1171	26	915	1086	58	968	845	184	1083	584	398	1130	5.0
Automapolyblock with ceiling insul.	D1	1521	22	569	1359	34	719	1153	60	899	807	164	1141	4.1
Banbrick with ceiling insulation	E1	1304	35	773	1211	80	821	927	229	956	693	402	1017	4.4

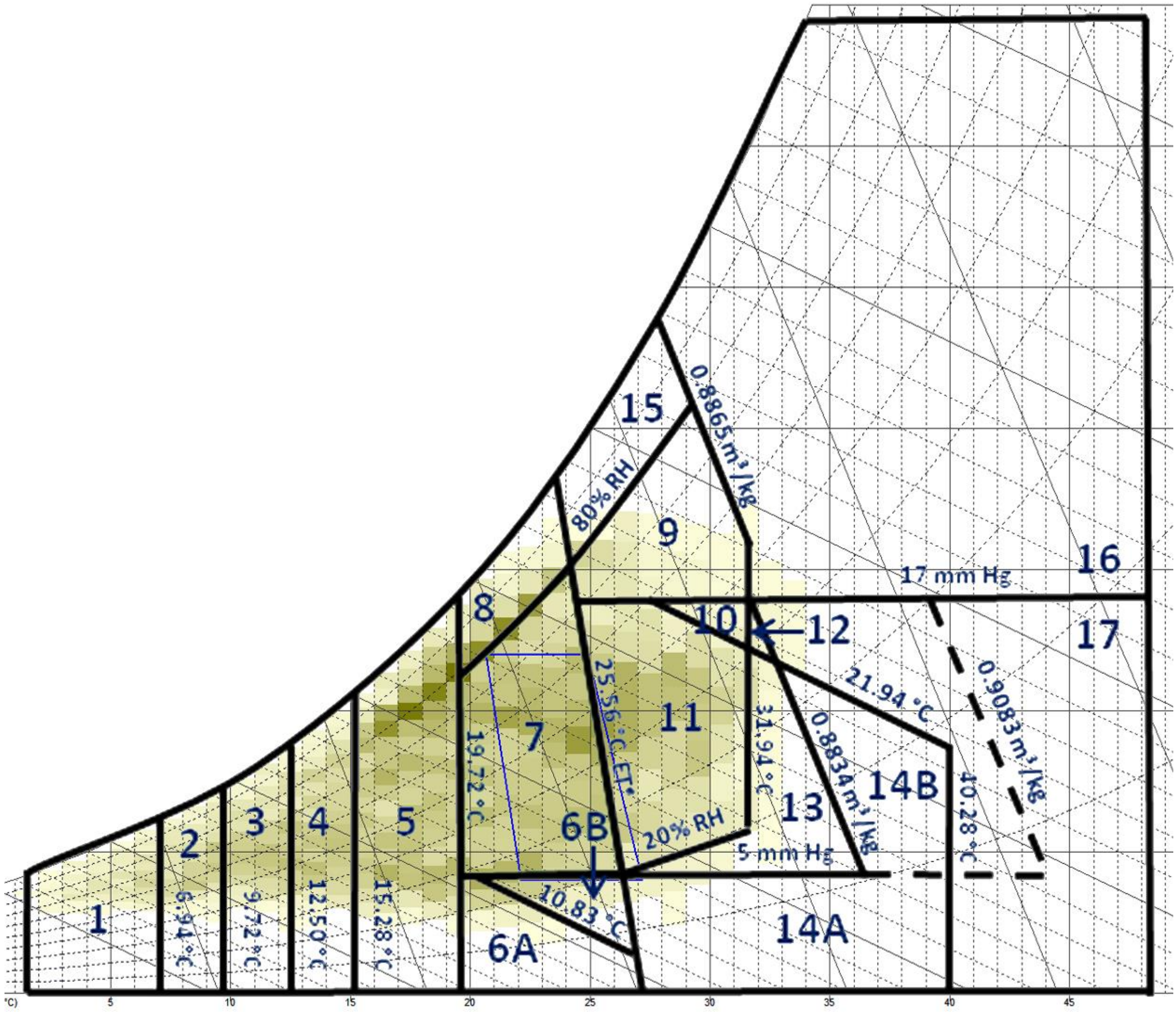


Figure 12: An overlay of the Central Pretoria (Forum) climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

3.1 Cwb (Warm temperate, Winter dry, Warm summer)

This relatively high lying climatic region covers 12.1% of the surface area and is also known as the “Highveld”. It includes Johannesburg and parts of Pretoria. Strategies that can be considered include Sun Shading of Windows, heat gains in winter and to a lesser extent Fan Forced Ventilation Cooling. The best IBT’s with regards energy requirement are class A, C, F, G1 and D1 and for comfort hours are C, B, F, G1 and D1. (Table 14).

Table 14: Quantified annual energy requirement in kWh (Top table) and number of comfortable hours (Bottom table) for Köppen climatic classification Cwb (Author)

Köppen-Geiger climatic regions	Cwb																						
Building system (kWh)	Class	Bethal			Bethlehem			Ermelo			Estcourt			Johannesburg OR Tamb			Pretoria Irene			Standerton			Rating
		H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	H.L	C.L	T.L	
LSF	A	20	2937	2957	174	1788	1962	126	1745	1872	54	2778	2831	113	2073	2185	40	2775	2814	17	3136	3154	3.6
Masonry	G	368	4396	4765	1046	2522	3568	825	2081	2906	521	3910	4431	727	2757	3485	429	4068	4497	350	4891	5241	2.2
Automapolyblock	D	159	5766	5925	527	3961	4488	398	3891	4289	252	5282	5534	372	4191	4563	202	5302	5504	152	6171	6323	1.7
Banbrick	E	709	5819	6528	1587	3370	4957	1320	3015	4336	910	5259	6169	1148	3684	4832	758	5244	6002	684	6435	7118	1.6
Goldflex 800 seismic	C	41	2867	2907	242	1624	1867	182	1412	1594	91	2675	2766	155	1880	2035	66	2697	2764	39	3108	3147	3.7
Imison 3	B	8	3253	3261	93	2058	2151	66	2067	2133	30	3089	3118	60	2366	2427	20	3056	3076	8	3432	3439	3.3
BESA 2	F	149	2144	2293	612	1019	1631	480	846	1326	249	2083	2332	393	1191	1584	196	2085	2281	137	2424	2561	4.6
Masonry with ceiling insulation	G1	158	1970	2128	624	841	1465	496	676	1171	263	1918	2181	400	1053	1453	202	1894	2096	148	2160	2308	5.0
Automapolyblock with ceiling insul.	D1	16	2999	3015	141	1822	1962	107	1684	1791	48	2785	2833	92	2060	2152	35	2830	2865	15	3189	3204	3.6
Banbrick with ceiling insulation	E1	473	3112	3585	1125	1386	2511	956	1224	2180	624	2946	3570	788	1655	2443	501	2799	3300	455	3512	3967	3.0

Köppen-Geiger climatic regions	Cwb																						
Building system (Hours)	Class	Bethal			Bethlehem			Ermelo			Estcourt			Johannesburg OR Tamb			Pretoria Irene			Standerton			Rating
		T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	T.H	T.C	Com	
LSF	A	1005	163	944	653	508	951	583	416	1113	931	222	959	619	328	1165	859	162	1091	1037	155	920	4.3
Masonry	G	621	415	1076	311	898	903	253	809	1050	553	483	1076	299	696	1117	533	455	1124	661	388	1063	4.5
Automapolyblock	D	910	271	931	542	605	965	492	545	1075	824	322	966	542	452	1118	772	280	1060	956	252	904	4.2
Banbrick	E	764	446	902	443	816	853	379	761	972	694	485	933	425	674	1013	650	472	990	809	409	894	4.0
Goldflex 800 seismic	C	616	298	1198	283	800	1029	233	687	1192	578	388	1146	267	572	1273	527	304	1281	685	271	1156	5.0
Imison 3	B	1001	145	966	622	451	1039	542	380	1190	911	199	1002	587	292	1233	840	145	1127	1028	139	945	4.5
BESA 2	F	614	419	1079	305	916	891	249	830	1033	567	478	1067	281	707	1124	505	450	1157	662	384	1066	4.5
Masonry with ceiling insulation	G1	509	446	1157	211	949	952	170	895	1047	457	524	1131	200	740	1172	403	491	1218	575	413	1124	4.7
Automapolyblock with ceiling insul.	D1	770	206	1136	433	636	1043	360	531	1221	717	283	1112	390	420	1302	664	196	1252	833	188	1091	4.9
Banbrick with ceiling insulation	E1	655	431	1026	355	867	890	286	817	1009	609	482	1021	335	706	1071	561	466	1085	704	399	1009	4.3

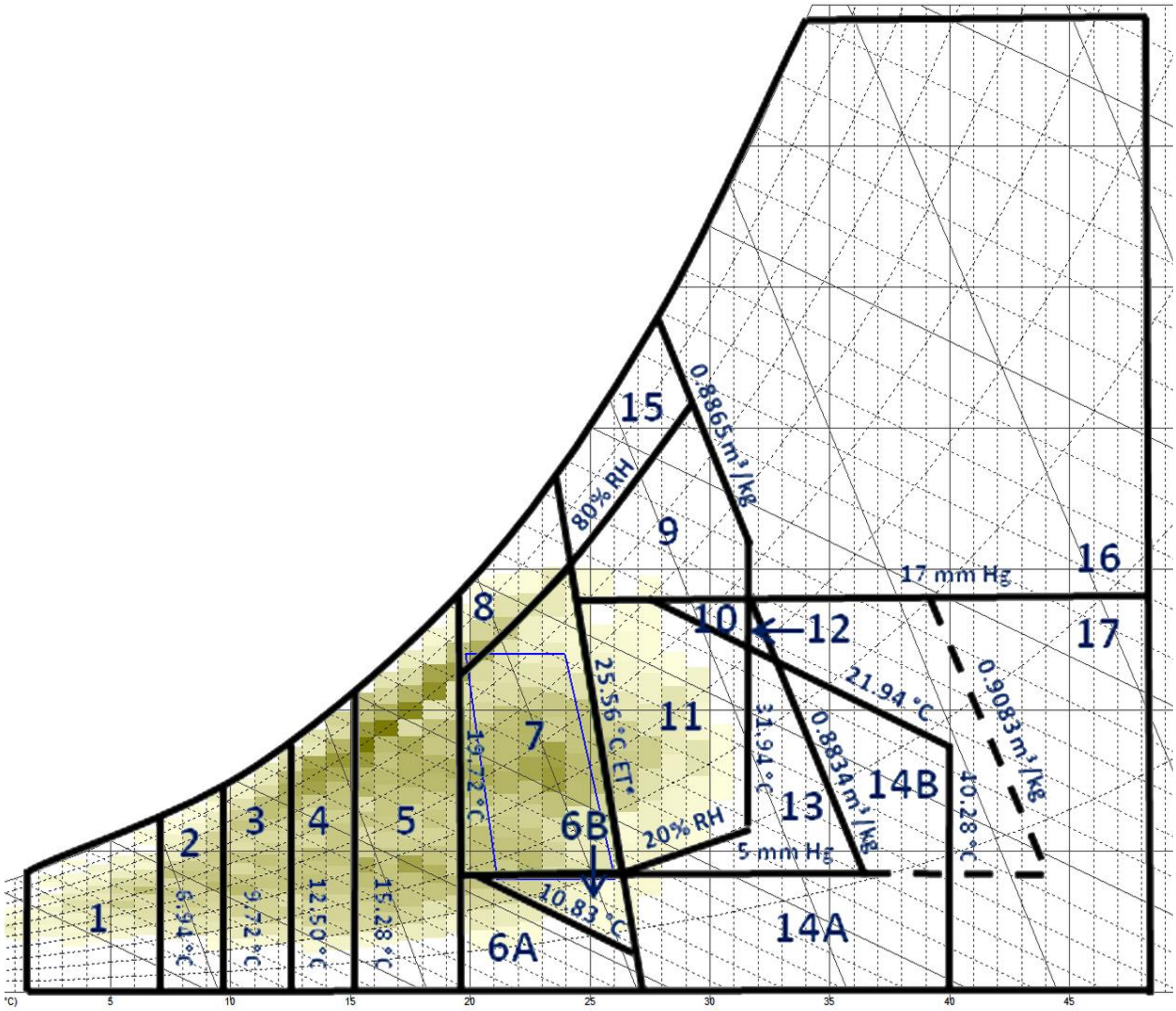


Figure 13: An overlay of the Johannesburg (OR Tambo Airport) climate on the Watson and Labs psychrometric chart to illustrate the fundamental climate characteristics. (Author)

4 Conclusions

The analysis above clearly indicate that IBT's perform well in all the climatic regions found in South Africa. Although this chapter concentrated on the thermal performance of the various systems many other factors also need to be considered before a final selection is made.

The psychrometric chart overlays provided some insight into the climatic characteristics of the various regions that lead to specific energy requirements and impacts directly on the number of hours that a particular structure would be comfortable. This is also a direct indicator of which passive measures would be most appropriate to make the building more comfortable.

Currently 0.2% of the country's area is equatorial, 70.89% arid and 28.91% has a warm temperate climate. Previous chapters indicated that with climate change the western parts of the country will progressively become hotter and dryer whilst the eastern parts will increasingly change to higher rainfall areas. The current small tropical area is likely to extend down to East London in a 100 year's time.

One of the elementary design mistakes, informed more by fashion than by reason, is architects' infatuation with over-glazing. This could lead to both overheating in summer and undercooling in winter or unwarranted air-conditioning. The study indicates that in all climatic regions of South Africa Sun Shading of Windows is highly beneficial.

When selecting an appropriate IBT for the delivery of social infrastructure with regards climate considerations four main criteria must be taken into account. The first criterion is the current Köppen-Geiger climatic region, the second the thermal performance of the actual building system under consideration, the third the most appropriate passive strategy to make it more comfortable and the fourth is the expected climate change over time.

A step wise worked example is described below. In this example it assumed that a new school needs to be designed near Bloemfontein in the township of Mangaung.

Step 1: In this step refer to the CSIR Köppen-Geiger map to determine the main climatic region. The detailed tables lists 38 cities and towns to make the climate identification easier.

Step 2: Once the climatic region has been determined go to the specific detailed tables above for a particular climatic region that summarizes the performance for a particular ABT System within that climatic region. The one that would be best from a climatic point of view would be the system with the least kWh energy required on an annual basis to make it comfortable.

Step 3: Once the system with best thermal/ energy performance has been determined, the designer can determine the set of most appropriate passive strategies that could be used to make it even more comfortable, especially during periods when the temperature/ humidity combinations would be outside the bioclimatic comfort regions described in Figure 3 and 13. For example in the case of Bloemfontein the following passive strategies would be most beneficial. (Conradie, 2013):

- Sun Shading of Windows (In Summer)
- Internal Heat Gain
- Passive Solar Gain Low Mass
- Passive Solar Gain High Mass

Step 4: As a final check consider the expected long term climate change by referring to the climate change maps. (Conradie, 2013). Read this in conjunction with the detailed CSIR climatic map in Figure 1. This will give you an indication of the expected change in Köppen-Geiger climatic category. As a general rule the West of the country will get significantly drier and the East much wetter and tropical within the next 100 years.

A good understanding of the basic principles using bioclimatic principles will lead to far better “climate aware” and environmentally conscious energy efficient architecture.

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