7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

ibpc2018.org | #ibpc2018

Optimal passive design strategies for nearly zero-energy dwellings in different Chilean climates using multi-objective genetic algorithms

Daniela Besser[1,*] and Frank U. Vogdt [1]

[1]Technische Universität Berlin, Berlin

[*]*Corresponding email: d.besserjelves@campus.tu-berlin.de*

ABSTRACT
At present, most developed countries attempt to highly diminish the energy consumption of buildings towards nearly zero-energy performances. This study assesses passive design strategies by means of multi-objective optimizations with genetic algorithms, aiming to minimize the heating and cooling demand of typical single-family dwellings in Chile. The results show that the thermal transmittance and airtightness of the whole building envelope should be highly improved from the current limiting values in all assessed locations. Complementarily, strategies for managing overheating would be crucial for avoiding to shift the heating demand into cooling. With this regard, the use of thermal mass, natural ventilation and shading devices in the east and west façades would be highly determining for achieving a balance between the two conflicting objectives throughout climatic zones in Chile.

KEYWORDS
Low energy dwellings, passive design, energy performance, multi-objective optimizations.

INTRODUCTION
The Chilean government aims to highly improve the energy-environmental quality of new Chilean dwellings to comparable standards with the OECD countries by 2035 (Ministerio de Energía, 2015). However, the current Chilean Thermal Regulation (TR) only limits the thermal transmittance of the major building envelope components of residential buildings, being its levels usually not enough for achieving low energy, high quality homes, as demonstrated by several studies (Bustamante et al., 2009; OECD, 2012). Complementarily, a 'Code for Sustainable Homes' (CSH) was published in 2014 and recently amended in 2018 by MINVU, highly tightening the energy-environmental requirements of dwellings when compared with the compulsory ones. This standard might set the path towards the necessary update of the TR, imperative for achieving low energy dwellings by 2035. Consequently, this study assesses its impact and explores the remaining gap for achieving nearly zero-energy demands in Chile, using multi-objective optimizations with evolutionary genetic algorithms, which is a probabilistic search technique based on nature that assumes that in a random initial population of individuals (being here each individual a certain combination of design variables), natural selection would foster the survival of the fittest. Their reproduction by recombination (i.e. crossover), together with mutations, would convey robustness and diversity to the new population, evolving until a solution is found (Eiben and Smith 2003). Having more than one objective to optimize would lead to a set of optimal solutions, i.e. Pareto front, being all of them equally suitable when no other objective or constraint exists (Deb et al., 2002).

METHODS
The research uses Design Builder v5 software to perform multi-objective optimizations to a Case Study (CS) in four climatic zones (Z) of Chile (See Figure 1). The CS is a 114m^2 single-family, detached, two-story dwelling, which is one of the most built housing typologies in the

country according to the National Statistics Institute (www.ine.cl). For the external walls, both brickwork (CS-A) and timber-frame (CS-B), the most used building systems for single-family dwellings, were assessed. The new CSH requests minimum heat capacity levels per m^2 of building element for each climatic zone, calculated according to ISO 13786:2007 (Annex A) and classified into light, medium and heavyweight. Accordingly, a typical 140mm brickwork wall represents a medium weight solution and a typical timber-frame wall a lightweight one. In both cases a lightweight timber-frame roof and a medium weight concrete slab-on-ground were used. With regards to the simulations, the software optimizes with a non-dominated sorting genetic algorithm (NSGA-II) developed by Deb et al. (2002). Two objective functions were used: to minimize the heating demand and to minimize the cooling demand of the CS; simulating with ideal loads, at 20°C and 26°C (25°C in ZI) operative temperature respectively, whenever when demand. Each story was considered a single thermal zone with constant internal gains of 4.8 W/m^2. As design variables, ten passive design strategies were simultaneously tested, each of them ranging between two to four levels, which are summarized in Table 1 and briefly described below. The levels in bold in Table 1 were used for the 'reference cases SH', that assess the U-values and airtightness suggested by the CSH, whereas the 'reference cases TR' evaluate the CS when minimally complying with the TR. The optimizations were set to a maximum of 200 generations, with an initial population of 20 individuals and a maximum of 50 per generation, and crossover and mutation rates of 0.9 and 0.5 respectively.

- Opaque envelope **(Env)**: this parameter varies the U-value of the external walls, roofs and suspended floors in four levels, progressively increasing them from the CSH values.
- Floor-on-ground **(FGr)**: its insulation level was separately assessed, since it is not regulated by the TR and since the perimeter vertical insulation proposed by the CSH would have a low impact according to a previous study (Besser and Vogdt, 2017). Instead, horizontal insulation under the slab was assessed in three levels, together with a non-insulated option.
- Windows **(Win)**: the CSH levels plus three more options that are currently available on the market were tested, varying both the U- and g-values of windows. Since the TR still allows single-glazing along the country when small windows' proportion, the reference cases TR were simulated using O1 in all locations (See Table 3).
- Window-to-wall ratio (WWR) on the North **(wwN)** and on the East-West façades **(wwE)**: Both the TR and the CSH limit the WWR according to the windows' U-value, the former for the whole building and the latter for each façade. Generally speaking, the colder the climate, the smaller the WWR that is allowed in both standards. This parameter was separately assessed for the North and for the East-West façades, assuming the lowest tested values for the reference cases TR and SH, and a constant 5.5% WWR on the South façade.
- Overhang Nord **(OvN)**: It assesses the suitability of a fixed horizontal shading device above the North windows to help seasonally regulating solar access.
- Temporary shades on the East and West facades **(ShE)**: Evaluates using external blinds on the East and West windows when internal temperatures are above 23°C (22.5°C in ZI).
- Infiltration rate **(n50)**: The limiting airtightness levels proposed by the CSH and two further levels were tested for each location. The values were normalized according to the DIN V 18599-2:2016-10 procedure, and 1 h^{-1} (14.28 h^{-1} at 50Pa) was assumed for the TR cases.
- Ventilation for cooling **(VfC)**: All cases consider natural ventilation for air quality purposes that seasonally varies according to DIN V 18599-2:2016-10. In addition, ventilation for cooling was assessed, increasing in 3 h^{-1} the ventilation rate when internal temperatures are above 23°C (22.5°C in ZI) and they are not below the external one.
- Internal thermal mass **(ThM)**: In CS-A, two types of internal partitions were assessed: lightweight timber-frame (L) and medium weight 140mm brickwork partitions (M), while a 120mm concrete slab remained constant. In CS-B, the timber-frame internal partitions

remained constant, but the timber-frame slab was tested with (M) and without (L) a 50mm concrete screed. For the TR and SH reference cases the lightweight options were used.

Table 1. Design variables and their levels

Parameter [unit]	Location A	Location D	Location E	Location I
Env [See Table 2]	**E1**	**E4**	**E5**	**E9**
	E4	E5	E7	E10
	E5	E7	E8	E11
	E7	E8	E10	E12
FGr [W/m^{2}K]	**3.6**	**3.6**	**3.6**	**3.6**
	1.2	1.2	1.2	1.2
	0.6	0.6	0.6	0.6
	0.3	0.3	0.3	0.3
Win [See Table 3]	**O1**	**O3**	**O4**	O4
	O2	O5	O5	**O5**
	O3	O6	O6	O6
	O4	O7	O7	O7
wwN [%]	**10**	**10**	**10**	**10**
	40	40	40	40
	70	70	70	70
OvN [m]	**-**	**-**	**-**	**-**
	0.4	0.4	0.4	0.4
	0.8	0.8	0.8	0.8
wwE [%]	**10**	**10**	**10**	**10**
	40	40	40	40
ShE [Yes/No]	Y	Y	Y	Y
	N	**N**	**N**	**N**
n50 [h^{-1} at 50 Pa]	**8**	**5**	**5**	**4**
	6	4	4	3
	4	3	3	2
VfC [Yes/No]	Y	Y	Y	Y
	N	**N**	**N**	**N**
ThM [Light/Medium]	**L**	**L**	**L**	**L**
	M	M	M	M

Table 2. Opaque envelope properties

Env	U-value [W/m^{2}K] wall	roof	floor
E1[A]	2.10	0.84	3.60
E2[D]	1.90	0.47	0.70
E3[E]	1.70	0.38	0.60
E4	0.80	0.38	0.70
E5	0.60	0.33	0.60
E6[I]	0.60	0.25	0.32
E7	0.45	0.28	0.50
E8	0.35	0.25	0.39
E9	0.35	0.25	0.32
E10	0.32	0.20	0.32
E11	0.25	0.15	0.28
E12	0.20	0.12	0.28

[A,D,E,I] Limiting U-values per climatic zone according to the TR. In zone A, a better U-value than the limiting one (4.0) was used for the walls, since the simulated constructive systems achieve better U-values even when uninsulated.

Table 3. Windows (openings) properties

Win	U-value [W/m^{2}K] glass	frame	g-value [-]
O1	5.8	5.8	0.86
O2	5.7	5.8	0.50
O3	2.8	5.8	0.76
O4	2.8	2.0	0.76
O5	1.8	2.0	0.72
O6	1.3	1.8	0.64
O7	0.8	1.3	0.58

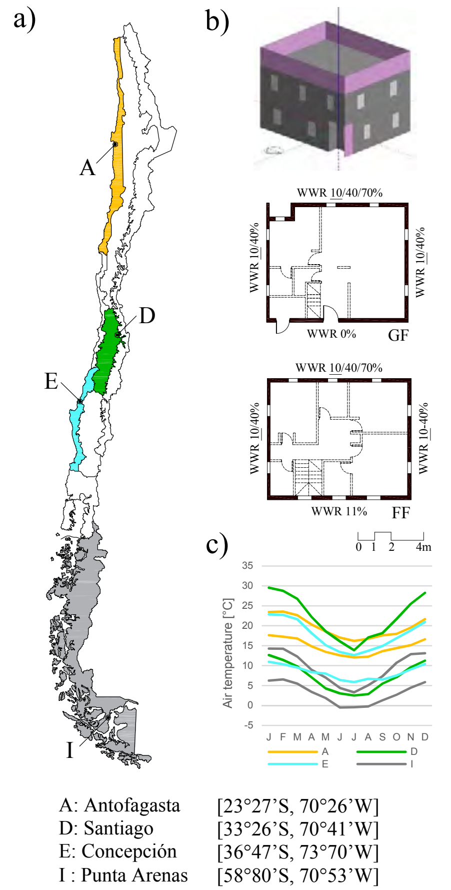

Figure 1 a) Climatic zones (CSH) and representative locations, b) 3D model and plans of the case study, and c) average highest and lowest air temperature per location (IWEC weather files used for the simulations)

RESULTS AND DISCUSSION

The optimizations results are shown in Figure 2, highlighting the Pareto front (OP) and conveying the energy demand of the Pareto point with the lowest heating (OP_h) and the one with the lowest cooling (OP_c) for each case. The reference performances TR and SH were added, demonstrating that a high reduction in both, the cooling and especially the heating demand could be achieved in zones ZD, ZE and ZI when tightening the envelope's thermal transmittance and airtightness as proposed by the CSH. Furthermore, it becomes clear the high potential for achieving low energy dwellings in all locations when properly combining passive design strategies. Nevertheless, it becomes clear as well that the cooling demand could highly increase from the reference performances TR and SH and become even higher than the heating demand, especially in the warmer locations ZA and ZD, and in the lightweight cases. Moreover, it evinces that some combinations of parameters could have a counter-productive effect when aiming to diminish the heating demand, shifting it into cooling or vice versa.

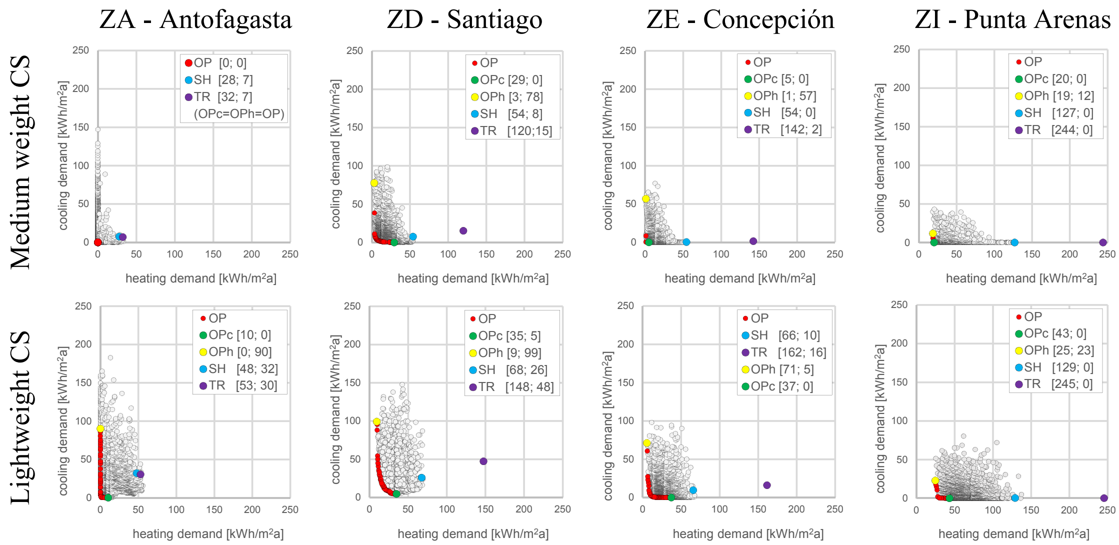

Figure 2. Optimization results plus reference performances TR and SH

Consequently, each Pareto front was analysed, aiming to identify those parameter combinations and levels that would lead to the optimal energy performances in each location. Since the Pareto front is the set of solutions not dominated by other solutions (Deb et al. 2002), and since minimizing the heating and the cooling demand are conflicting objectives, the lower the heating, the higher the cooling and vice versa for every Pareto point, which makes possible to simultaneously list the solutions by ascending heating and descending cooling demand. The outcomes are summarized in Tables 4 to 11, conveying the average heating (AvH) and cooling (AvC) demand of groups of solutions that achieve similar performances and showing the relationship between the ten design variables and the respective levels that would lead to Pareto solutions. In addition, the amount of Pareto points in every group of solutions is given by its frequency (Freq), being 100% the total amount of points within the Pareto front. The set of points with the lowest heating are located on the top of each table, the solutions with the lowest cooling at the bottom, and the trade-offs points are located in between. The highlighted level when grouped conveyed corresponds to the OP_h and OP_c point accordingly. It is worth mentioning that not all combinations among the grouped levels would lead to Pareto solutions.

When looking at Tables 4 to 11, it becomes clear that tightening the envelope thermal transmittance to the best levels together with increasing thermal mass are determining strategies to drastically reduce both the heating and the cooling demand in all locations and for both constructive systems, since these levels are present in 100% of the points forming the Pareto fronts. The OP_h points had additionally in common not considering ventilation for cooling, nor shading devices or overhang, plus the highest wwN, windows with the best U-values, the best n50 rate and the highest or middle floor insulation level, but they resulted in extremely high cooling loads when compared with the TR reference cases in all locations, in spite of reducing heating by 90 to 100%. On the contrary, the OP_c points had in common to allow VfC, to consider the lowest wwE with shading devices, plus windows with the lowest g-values and either a short or a large overhang, in addition to the previously mentioned levels of Env and ThM. These cases would eliminate the need of cooling in all locations, except for the lightweight CS-B in ZD, where nonetheless a 90% reduction would be achieved when compared with the TR performance. Moreover, the resulting heating demands would be 75 to 100% lower than in the TR reference cases in all locations. In ZA it would even be possible to achieve zero energy demands for space conditioning when enough levels of thermal mass, as in CS-A. Finally, the trade–off Pareto points attempt a balance between the two conflicting objectives. Here, most

Table 4. Optimal combinations in Antofagasta for Case Study A (17 points = 100%)

Env	ThM	Win	VfC	ShE	wwN	wwE	OvN	n50	FGr	AvH	AvC	Freq
E7	M	O5	Y	Y	40	10	0.4/0.8	4/6/8	0.3/0.6/1.2/3.6	0	0	59%
						40	0.8	4/6/8	1.2/3.6	0	0	29%
					10	40	-/0.4	4	0.3/0.6	0	0	12%

Table 5. Optimal combinations in Antofagasta for Case Study B (78 points = 100%)

Env	ThM	Win	VfC	wwN	wwE	ShE	n50	OvN	FGr	AvH	AvC	Freq
E7	M	O5	N	70	10	N/Y	4	-/0.4	0.3/0.6/1.2/3.6	0	69	14%
				40	10	Y	4	-/0.4	0.3/0.6/1.2	0	34	12%
			Y	70	10	Y	4	0.4	0.6/3.6	0	20	3%
				40	10	N	4	-	0.3/0.6	0	14	3%
						Y	4/6	-/0.4/0.8	0.3/0.6/1.2/3.6	0	4	18%
				10	40	Y	4	0.4/0.8	0.3/0.6/1.2/3.6	1	2	9%
					10	Y	4/6/8	-/0.4/0.8	0.3/0.6/1.2/3.6	3	0	22%
		O2	Y	10	10	Y	4/6/8	-/0.4/0.8	0.3/0.6/1.2/3.6	7	0	21%

Table 6. Optimal combinations in Santiago for Case Study A (40 points = 100%)

Env	ThM	n50	VfC	ShE	Win	wwN-wwE	OvN	FGr	AvH	AvC	Freq
E8	M	3	N/Y	N	O7	70-40	-	0.3/0.6	3	58	5%
			Y	Y	O7	70-40	-/0.4/0.8	0.3/0.6/1.2/3.6	5	7	20%
						70-10/40-40	0.4/0.8	0.3/0.6/1.2/3.6	8	3	25%
						40-10	-/0.4/0.8	0.3/0.6/1.2/3.6	13	1	23%
					O6/O7	10-10	-/0.4/0.8	0.3/0.6/1.2/3.6	26	0	28%

Table 7. Optimal combinations in Santiago for Case Study B (51 points = 100%)

Env	ThM	Win	ShE	VfC	wwN-wwE	n50	FGr	OvN	AvH	AvC	Freq
E8	M	O7	N	N	70-40/70-10	3	0.3	-	10	84	8%
			Y	N/Y	70-40/70-10/40-40	3	0.3	-/0.4/0.8	12	35	18%
				Y	70-10/40-40	3/4	0.3/0.6	-/0.4/0.8	16	20	31%
					40-10	3/4	0.3/0.6	-/0.4/0.8	19	13	31%
					10-40/10-10	3/4	0.3/0.6/1.2/3.6	-/0.4/0.8	27	7	43%

Table 8. Optimal combinations in Concepción for Case Study A (13 points = 100%)

Env	ThM	Win	VfC	ShE	wwN-wwE	n50	FGr	OvN	AvH	AvC	Freq
E10	M	O7	N	N	70-40	3	0.3	-	1	57	8%
			Y	N	70-40	3	0.3	-	1	8	8%
				Y	70-40	3/4	0.3/0.6/1.2	-/0.4/0.8	3	0	69%
					70-10/40-40	3	0.3	-/0.8	5	0	15%

Table 9. Optimal combinations in Concepción for Case Study B (47 points = 100%)

Env	ThM	Win	ShE	VfC	wwN-wwE	FGr	n50	OvN	AvH	AvC	Freq
E10	M	O7	N	N	70-40	0.3	3/4	-/0.4	6	67	6%
			Y	N	70-40/70-10	0.3	3	-/0.4	7	21	9%
				Y	70-40/70-10	0.3	3/4	-/0.4/0.8	10	5	15%
					40-40/40-40	0.3/0.6	3/4/5	-/0.4/0.8	14	1	21%
					10-40/10-10	0.3/0.6/1.2/3.6	3/4/5	-/0.4/0.8	26	0	49%

Table 10. Optimal combinations in Punta Arenas for Case Study A (7 points = 100%)

Env	ThM	Win	n50	FGr	wwN	VfC	wwE	OvN	ShE	AvH	AvC	Freq
E12	M	O7	2	0.3	70	N	10	-	Y/N	19	6	29%
						Y	10/40	-/0.4	Y/N	20	0	71%

Table 11. Optimal combinations in Punta Arenas for Case Study B (17 points = 100%)

Env	ThM	Win	n50	FGr	VfC	wwN	wwE	OvN	ShE	AvH	AvC	Freq
E12	M	O7	2	0.3	N	70	10	-/0.4	Y/N	26	17	24%
					Y	70	10-40	-/0.4/0.8	Y/N	31	1	41%
						40	10-40	-/0.4/0.8	Y/N	39	0	35%

combinations have additionally in common to allow VfC, windows with the lowest U- and g-values, the best n50 levels and ShE. The WWR on the North and on the East-West façades varies depending on the case and location, highly determining the degree of compromise between the objectives. The final election of a best case among each Pareto front would depend on a complementary factor, such as the heating and cooling systems to be used, their efficiency, their energy source, its price, its primary energy factor, the costs of the design strategies, etc.

CONCLUSIONS

It would be possible to highly diminish the heating and cooling demand of Chilean dwellings when tightening the envelope thermal transmittance and n50 values as the CSH proposes. Moreover, a high improvement potential remains beyond. In fact, the energy demand for space conditioning could approach to zero in all assessed locations when properly combining passive design strategies as the ones assessed in this study. However, attempting to minimize both demands are conflicting objectives and therefore, care should be taken to avoid shifting the heating savings into cooling demands or vice versa. Since some strategies attempt minimizing heating and others pursuit cooling reductions, a balance should be aimed and thus the interaction among strategies becomes highly relevant, which confirms the appropriateness of multi-objective analyses when searching for zero-energy buildings and the importance of the interaction between the design strategies when optimizing buildings' energy performance.

ACKNOWLEDGEMENT

This study was undertaken as part of a doctoral study in the Building Physics Department of the Technische Universität Berlin, financed by the German Academic Exchange Office DAAD.

REFERENCES

Besser, D. and Vogdt, F.U. 2017. First steps towards low energy buildings. How far are Chilean dwellings from nearly zero-energy performances?. *Energy Procedia,* 132, 81-86.

Bustamante, W., Rozas, Y., Cepeda, R., Encinas, F. and Martinez, P. 2009. *Guía de diseño para la eficiencia energética en la vivienda social.* Santiago: MINVU & CNE.

Deb, K., Pratap, A., Agarwal, S. & Meyarivan, T. 2002. A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Transactions on evolutionary computation*, 6(2), 182–197.

Eiben, A.E. and Smith, J.E. 2003. *Introduction to evolutionary computing*. New York: Springer.

DIN. 2016. *Prestandard DIN V 18599-2:2016-10*, Energy efficiency of buildings - Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting - Part 2: Net energy demand for heating and cooling of building zones. Berlin: Beuth Verlag.

ISO. 2007. *Standard ISO 13786:2007*, Thermal performance of building components - Dynamic thermal characteristics - Calculation methods. Switzerland: International Organization for Standardization.

Ministerio de Energía. 2015. *Energy 2050. Chile's energy policy.* Santiago: Ministerio de Energía.

MINVU. 2018. Estándares de construcción sustentable para viviendas de Chile. Santiago: Ministerio de Vivienda y Urbanismo.

OECD. 2012. *OECD Economic Surveys: Chile 2012.* Paris: OECD Publishing.