3.2 Comfort variations in Pareto's solutions

The previous paragraphs show a good robustness of the MOO method to the epistemic uncertainty introduced by the choice of solar models. However, substantial differences can be highlighted when assessing the comfort performance. The thermal comfort indicators used for the investigation is the discomfort weighted time (WDT) index, as proposed by the EN 15251 (CEN, 2007c) through the degree hours criteria. The graph in Fig. 4 clearly shows the WDT variations of REF1 semi-detached house caused by the choice of the models when NPV and EP are choses as objectives. This greater sensitivity of WDT to solar models has repercussions on the robustness of MOO procedure when three different goals such as NPV, EP and WDT are considered. The Pareto's fronts in Fig. 5 show a greater dispersion of the results obtained with the three different combinations of solar models. In this case, therefore, the choice of a combination of models leads to the selection of different optimal mix of ESMs.

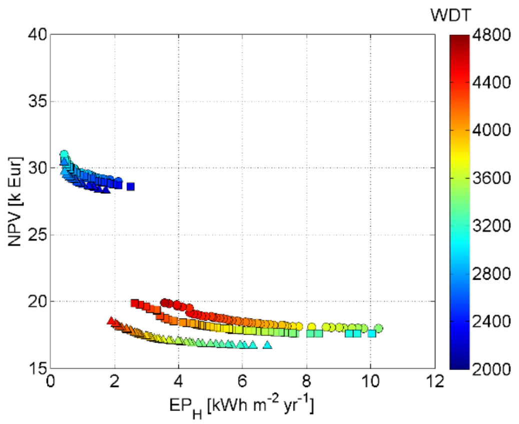

Fig. 4 – Pareto´s fronts of the semi-detached house REF 1 with south oriented windows. The data points are colored according to WDT while circle referred to C1, square to C2 and triangle to C3.

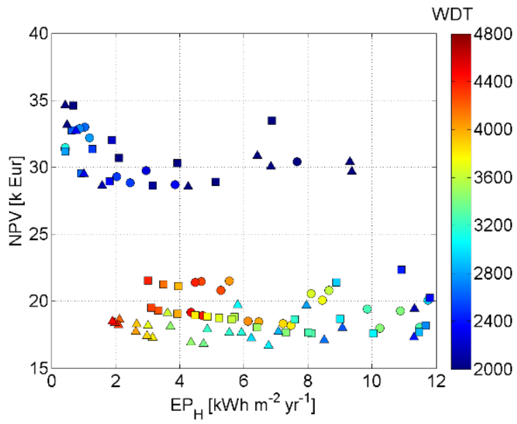

Fig. 5 – Pareto´s fronts of the semi-detached house REF 1 with south oriented windows obtained with a 3 objective optimization. The data points are colored according to WDT while circle referred to C1, square to C2 and triangle to C3.

4. Conclusion

This work assessed the robustness of NSGA II in finding optimal building energy refurbishment when three different couples of solar irradiation models are adopted. The results show the variability of the EP index in the range of ± 3 % for most of the test cases for the simulation performed on the initial state.

As regards Pareto´s fronts, the utilization of the C1 models makes some solutions not-dominated instead of dominated as they are for in cases C2 and C3. In particular, these new optimal solutions have higher insulation thickness and triple glazings due to the lower incident solar irradiation provided by C1 models.

Notice that slight differences are present in the mix of ESMs able to guarantee either the minimum NPV or the minimum EP. Again, the greatest differences occur with C1, which tends to increase the thickness of the insulating layers for both the optima.

The NSGA-II then shows a good robustness when the solutions are optimized in terms of NPV and EP. In fact, substantial changes are noted on the thermal discomfort of optima solutions. This greater sensitivity of the WDT index to solar irradiation implies a decrease of MOO robustness when the minimization of WDT becomes an objective.

5. Nomenclature

Symbols

A	area (m^2)
COND	Condensing boiler
DH	Double glazing with high SHGC
S	Surface of dispersing envelope (m^2)
SG	Single Glazing
SHGC	Solar heat gain coefficient (-)
STD	Standard boiler
TH	Triple glazing with high SHGC
V	Conditioned volume (m^3)

References

Boland, J., Ridley B., Brown, B., 2008, *Models of diffuse solar radiation*. Renewable Energy, 33:584–116.

Bugler, J.W., 1977, *The determination of hourly insolation on an inclined plane using a diffuse irradiance model based on hourly measured global horizontal insolation*. Solar Energy, 19(5):477 – 491.

CEN European Committee of Standardization, 1999. *EN 12207:1999, Windows and doors. Air permeability – Classification*.

CEN, European Committee of Standardization, 2007a. *EN 15242:2007, Ventilation for buildings – Calculation method for the determination of air flow rates in buildings including infiltration*.

CEN European Committee of Standardization, 2007b. *EN 15459:2007, Energy performance of buildings - Economic evaluation procedure for energy systems in buildings.*

CEN European Committee of Standardization 2007c. EN 15251, *Indoor environmental input parameters for design andassessment of energy performance of buildings.*

Deb, K., Pratap, A., Agarwal, S., 2002. A Fast and Elitist Multi-objectives Genetic Algorithm: NSGA-III, *IEE Transactions on Evolutionary Computation*, 6 (2):182-197

Erbs, D. G., Klein, S. A., Duffie, J. A., 1982, *Estimation of the diffuse radiation fraction for hourly, daily and monthly-average global radiation*. Solar Energy, 28(4): 293–302.

European Commission, 2010. *Directive 2010/31/EU of the European Parliament and of the council of 19 may 2010 on the energy performance of buildings (recast)*, Official Journal of European Union 153 (2010) 13 – 35.

European Commission. 2012. *Commission delegated regulation (EU) No 244/2012 of 16 January 2012*. Official Journal of European Union L81/18 (2012).

Ihm P., Krarti M., 2012. *Design optimization of energy efficient residential buildings in Tunisia*, Building and Environment, vol.58, p.81-90

Italian Parliament. 1976. *Law 373 Norme per il contenimento del consume energatico per usi termici negli edifici*.

Italian Parliament. 1991. *Law 10, Norme per l'attuazione del piano energetico nazionale in materia di uso nazionale dell'energia, di risparmio energetico e di sviluppo delle fonti rinnovabili di energia*

Liu, B.Y.H., Jordan, R.C., 1960, *The interrelationship and characteristic distribution of direct, diffuse and total solar radiation*. Solar Energy, 4(3):1 – 19.

Maxwell, E.L. 1987. *A quasi-physical model for converting hourly global horizontal to direct normal insolation*. Technical Report of Solar Energy Research Institute, SERI/TR-215-3087.

Penna, P., Prada, A., Cappelletti, F., Gasparella, A., 2015, *Multi-objectives optimization of Energy Efficiency Measures in existing buildings*. Energy and Buildings. In Press

Perez, R.R., Ineichen, P., Seals, R., 1990, *Modeling daylight availability and irradiance components from direct and global irradiance*. Solar Energy, 44(5):271–289

Perez, R.R., Ineichen, P., Maxwell, E.L., 1992, *Dynamic global-to-direct irradiance conversion models*. ASHRAE Transactions, 98(1): 354-369.

Pernigotto, G., Prada, A., Gasparella, A., Hensen, and J.L.M., 2014, *Development of a set of simplified building models for building simulation*. In 3rd Int. High Performance Building Conference, Purdue (U.S.).

Prada, A., Pernigotto, G., Cappelletti, F., Gasparella, A., Hensen, J.L.M., 2014a, *Robustness of multi-*

objective optimization of building refurbishment to suboptimal weather data. In 3rd Int. High Performance Building Conference, Purdue (U.S.).

Prada, A., Pernigotto, G., Baggio, P., Gasparella, A., Mahdavi, A., 2014b, *Effect of solar radiation model on the predicted energy performance of buildings*. In 3rd Int. High Performance Building Conference, Purdue (U.S.).

Prada, A., Pernigotto, G., Gasparella, A., Mahdavi, A., 2015, *Combined effects of diffuse fraction and tilted surface radiation models*. In ECPPM 2014 eWork and eBusiness in Architecture, Engineering and Construction, p. 251-257, Vienna (Austria).

UNECE, 2006. *Bulletin of Housing Statistics for Europe and North America*, Technical Report, United Nations Economic Commission for Europe.

Wright, J., Alajmi, A., 2005, *The robustness of genetic algorithms in solving unconstrained building optimization problems*. Proc. of 9th Building Simulation, p. 1361-1368.