EVALUATION OF THE INFLUENCE OF CLIMATE WARMING AND BUILDING AGEING ON BUILDING ENERGY CONSUMPTION

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ABSTRACT

This study uses a building energy simulation tool to model a real building in Torino, northern Italy. The focus of the research was to consider the combined effect of the predicted warming climate and building ageing on the building energy performance. The study projects global warming and building ageing effects into the future, using IPCC predicted scenarios and projections for building component ageing. Results from the climate-only simulation showed a dominant decrease in the building heating energy usage, which overrides the increase in the cooling load. The ageing study showed an increase in the building energy consumption due to components ageing, particularly the HVAC equipment. When combining the effects of climate and building ageing, the latter was found to have a significant impact on the overall future energy performance of the building.

INTRODUCTION

Climate plays a key role in the energy footprint of a building as a great share of the energy consumption is due to regulation of comfortable internal temperatures and relative humidity. Buildings can have long life spans and many buildings over 50 years of age are still occupied as homes and businesses - these are still expected to provide resident comfort. With a rise in global temperatures, there will be an expected increase in the cooling load for most buildings with air-conditioning systems. Previous studies on the influence of climate change on building energy performance show that in northern latitudes the reduction in heating demand will be the dominating factor, with a lower increase in the demand for cooling in summer (Pilli-Sihvola et al., 2010). On the other hand, in the southern latitudes, the increase in cooling demand is predicted to outweigh the reduction in heating energy load. The impact of global warming is expected to be exacerbated in urban areas due to the urban heat island effect. The energy penalty of environment overheating has been found to be very significant with dependence on the characteristics of the building, the climate zone and the urban environment (Santamouris et al., 2015). Along with climate variations, another factor affecting building energy performance over time is the ageing of building components. Buildings structure and equipment suffer from natural ageing and weathering with mechanical components degrading over time (ASHRAE, 2015). The gradual accumulation of these degradation effects results in reduced energy efficiency and performance of the building as a whole and may affect occupancy comfort.

To the authors´ knowledge, there have been no previous studies done that consider the combined effect of both climate warming and building ageing and degradation on future energy performance for buildings. Building ageing and imminent climate change lead to an urgent need for improving our knowledge about how the energy performance of current building stock will respond to this double impact. This study aims to fill that gap through a detailed modelling simulation of a real building, in northern Italy, including a number of climate warming and ageing scenarios. The building under investigation is in Torino (Italy), which sits on the border of the humid subtropical climate and oceanic zones, hence this building will experience both periods of significant space heating and cooling throughout the year. This paper will look at the effect of a warming climate on the energy demands of a recently refitted 19th century building using an advanced building modelling software, IDA ICE. The simulations will project over a 50-year period, from 2010 to 2060, and will include typical weather data for the location, which will be modified to reflect predicted climate change effects. Investigating not only climate change but also building equipment and component ageing, the present work will assess their combined impact on building's energy consumption, for a more realistic assessment of future building efficiency profiles.

BUILDING MODEL AND METHODOLOGY

The Torino building model

A demonstration building within the European funded FP7 TRIBUTE project was selected for the performance of a set of comprehensive simulations in order to study the effect of climate change and building ageing on building energy performance over several decades. The selected building for the study is a library building -the Library Italo Calvino, located in Torino city (Italy). The building, a masonry structure, consists of about 750 m^2 per floor (4 floors) and of 13,000 m^2 of external perimeter. It was built in the 19th century on the right side of the river Dora, as it originally housed a tannery and was retrofitted in 2006.

Information on the building envelope features and equipment was obtained from technical surveys and reports and entered as input to the simulation program IDA ICE. IDA ICE is an innovative whole-year detailed and dynamic multi-zone simulation application for the study of thermal indoor climate as well as the energy consumption of the entire building. Some of the main features of the Torino library model implemented in IDA ICE are the following:

- The building counts with a central core, approximately of 16m x 14m, with a load-bearing brick masonry. The side wings have concrete structure, and brick masonry. The roof is wooden with tiles coverage. External walls are in double bricks masonry. Walls and roof are provided with polystyrene foam insulation.
- Windows: double glazing clear panes with glazing U-value of 1.1 $W.m^{-2}.K^{-1}$.
- Window shading and blinds: Venetian and roll blinds with manual control with schedule always drawn on the inside of windows.
- The model takes into account thermal bridges and wind driven flow infiltration.
- Equipment: the model includes an AHU with supply air temperature set point at 21 °C and 30 kVA steam humidifier with 50% relative humidity target with return temperature and humidity control. The system works with VAV ventilation with pressure control.
- The heating system consists of two boilers Rendamax R307 with total nominal power of 548 kW. Emission is done by reversible fan coils in zones. Heating coil, cooling coil and air flow are defined according to specifications.
- The cooling system consists of an air cooled chiller Climaveneta 1952/SL-S of 411.6 kW nominal power. Distribution losses and emission are included in the model.
- Domestic hot water: produced by four electric water heaters, Ferroli Cube SG15, each with 1,5 kW.
- Lighting power density defined in the different rooms, with working hours schedule.
- Occupancy schedules are taken into account, with a number of 29 officials and an estimated number of people of 62/day. Total opening days are 240 and the occupancy profile is considered as a bimodal density distribution with two peak values around 10:00 and 16:00, and with a peak duration of two hours each.
- Weather data from ASHRAE IWEC2 database was used to model the baseline typical climate conditions at the location.

The IDA ICE building model, as defined with the default characteristics for the real building, was adopted as baseline case. Modifications on the different parameters of the model, such as building structure components, equipments efficiency and climate conditions were applied in a set of simulations in order to analyse the effect of climate change and ageing on the building energy performance.

Impact of climate change on building energy performance

The building model was run for climate change and building ageing separately and then all together. The results were then analysed to discover the impact of these changes on the energy performance of the building in the near future. The results are presented as heating and cooling final energy usage, which is the energy consumed on-site by the building to cover its space cooling and heating demand, respectively. The simulations are initiated in 2010 (baseline) with decadal climate change up to 2060. The climate change is defined on two IPCC scenarios based on varying future CO_2 emission levels. The IPCC synthesis scenario study (Bernstein et al., 2007) simulated a number of cases of CO_2 emission that were influenced by future human, economic and technological scenarios. Two scenarios were chosen for this study: A2 and B1. In the IPCC report, A2 is considered one of the worst case scenarios in the near future with an average global increase of 3.6 °C and a likely range of 2.0 °C to 5.4 °C. This scenario describes a very heterogeneous world over the next 50 to 100 years with high population growth, slow economic development and slow technological change. Another, more middling, scenario is B1 with an average rise by 2100 of 1.8 °C and a likely range of 1.1 °C to 2.9 °C. This scenario describes a convergent world with a large global population peak by the mid-century and rapid development of the economy towards a service and information driven economy. Extrapolating from the IPCC report, a future climate-warming trend was implemented into the building simulation tool (see table 1).

In terms of solar radiation, it has been reported a potential increase of 5% by 2035 (less cloudy days) (Aebischer et al., 2007). Following the approach by Aebischer et al., 2007, linearly extrapolating this from the baseline year for the period investigated, allows a solar radiation component to be added to the simulations. There still exist high uncertainty in the prediction of solar radiation variation due to climate change and its dependence of local conditions.

However, a sensitivity analysis in this study showed that the building energy performance is rather insensitive to this parameter compared to the temperature change.

Case	Year					
	2010		2020		2030	
			ΔT(°C)	ΔRd	ΔT(°C)	ΔRd
A2	Baseline		+0.56	3.0%	+0.85	4.4%
B1	Baseline		+0.62	3.0%	+0.82	4.4%
	2040		2050		2060	
	ΔT(°C)	ΔRd	ΔT(°C)	ΔRd	ΔT(°C)	ΔRd
A2	+1.14	5.8%	+1.47	7.2%	+1.83	8.7%
B1	+1.02	5.8%	+1.20	7.2%	+1.38	8.7%

Table 1. Temperature (ΔT) and solar radiation (ΔRd) variations from 2010 to 2060 for IPCC scenarios A2 and B1.

A further prediction of climate change is the increased likelihood of extreme climate events, such as the 2003 European heat wave that will strike with greater frequency, intensity and duration. Based on previous studies, heat wave conditions were simulated in this study by adopting a 6 °C temperature average increase for the summer (JJA) months and 1.83 °C for the non-summer part of the year for the latest A2 scenario, year 2060. These temperature modifications to the Torino climate file results in 50 days above 30 °C and a 90-percentile value of 34 °C, which are consistent with heat wave studies (Beniston, 2004).

Impact of building ageing on building energy performance

The building ageing was assessed through the ageing of its envelope and equipments components. Each component is characterized by many variables and parameters that may evolve with time: the ageing parameters. An ageing parameter is a quantity – parameter or variable – that will change over the years with the ageing of the building. It could be a quantity fixed within a year, like the thickness of insulation (a real parameter), or a quantity that evolves during the year like a set point (a variable). Most of the time, the ageing parameters of the Torino library case study are real parameters within the year, a fixed quantity, but become variable because they change over the years due to ageing.

The selection of the most important ageing parameters was an important part of this work. Some parameters may evolve over time but their evolution is difficult or impossible to predict because of changes in the usage of the building. For this study it was adopted that the usage of the building and of its rooms would be constant in time. This means that all the schedules, controls and set points are not considered as ageing parameters: they remain constant over the years in the building. Other parameters are also considered constant over time and are divided into two groups: the parameters that do not evolve over time, and the group of parameters that even if they evolve over time have no impact on the building energy performance. The first group are parameters that are identified mainly thanks to expert knowledge within the FP7 TRIBUTE project. The second group are parameters that evolve over the years but not sufficiently to affect the energy performance of the building, they are identified thanks to a sensitivity parametric study that will not be presented here. The expert group selected 11 parameters as potentially important for the building model. Only five of them had an effect on the energy consumption of the building greater than 2%: external wall U-value, roof U-value, heat emission due to appliances and heating and cooling production efficiencies.

Few documents assess the degradation of the performance of building components when ageing. Using information from database reports (ASHRAE handbook, 2015) and existing literature the degradation degree for the selected parameters was determined for the ageing study. The main reason for boiler efficiency deterioration is due to soot production from the combustion process which in turn coats the heat exchanger surfaces reducing the efficiency. According to the boiler manufacturer Babcock and Wilcox, 70% of boiler capacity is available for 30 years, after which a retrofit or an upgrade is generally needed (Pasi and Muller, 2007). Based on this, the degradation of the boiler in this study is set to reach a value of 70% after 30 years, which implies a 10% decadal degradation.

Year	Boiler efficiency	Chiller efficiency (COP)	Wall insulation- (thickness-thermal conductivity)	Roof insulation (thickness-thermal conductivity)	Internal loads
2010	0.89	2.29	5cm - 27mW/(m.K)	5cm - 36mW/(m.K)	x
2020	0.8	2.06	5cm - 30mW/(m.K)	5cm - 40mW/(m.K)	10%
2030	0.71	1.8	5cm - 35mW/(m.K)	5cm - 45mW/(m.K)	20%
2040	0.96	3	10cm - 27mW/(m.K)	10cm - 36mW/(m.K)	30%
2050	0.86	2.7	10cm - 30mW/(m.K)	10cm - 40mW/(m.K)	40%
2060	0.76	2.4	10cm - 35mW/(m.K)	10cm - 45mW/(m.K)	50%
Tendency /10 years	-10%	-10%	+10%	+10%	+10%

Table 2. Range of variation of each retained ageing parameters over 50 years

According to model predictions on the evolution of internal gains for different European countries, it is expected to have a 15% internal gains increment in multifamily residential buildings in Italy in the period from 2008 to 2050 (Elsland et al., 2014), which implies approximately a 4% decadal increase. However, a large uncertainty exists in the estimation of the variation of internal gains for different buildings in time. In particular, it is difficult to predict the internal heat gains attributed to users´ electronics and mobile devices which account for a large share of 30-40% of internal gains (Elsland et al., 2014). Considering this large uncertainty and that in a library building it is expected to have an internal gain decadal increase higher than for a residential building because of the presence of more users, in the present study it was adopted a 10% decadal increment of the internal load as a worst case scenario situation.

Chiller efficiency deteriorates over time due to the direct relationship between heat transfer and surface area. Heat transfer is optimised using cleaning to avoid pipes becoming fouled with algae, sludge, scale or contaminants which accumulate over time on the waterside of heat transfer surfaces. The COP of a chiller with proper chemical cleaning maintenance has been shown to drop in a 10% in 10 years (Bannai et al., 2008) due to mechanical deterioration only, which is the value adopted in the current study.

Wall insulation is subject to moisture cycles, shrinkage and deterioration over time. These factors will increase the U-value over the design conditions. Field studies on the performance of polystyrene foams have shown that these can absorb water during their lifetime, decreasing their thermal performance. For the case of XPS (expanded polystyrene foam) thermal degradation can range from 20-60% in 15 years in roofs and floor installations (Kehrer and Christian, 2012). For the case of below grade EPS (expanded polystyrene foam) the degradation in 15 years has been found to be lower, of the order of 6% (Insulfoam). However, there is a large uncertainty to constrain the degradation of the insulation material in a particular building, given that it is highly dependent on the humidity, construction characteristics, and orientation of the envelope components. An average conservative value of 10% decadal degradation of insulation thermal performance was adopted for this parameter in the present study. It should be remarked that further investigations should be done in order to derive parameterizations that allow predicting the degradation of materials as a function of environmental conditions and envelope properties for the purpose of building energy performance simulations.

For the simulations, a retrofit of the building is made in 2040 in order to see its impact on the energy consumption. The boiler and chiller are replaced in this year, thus increasing their efficiency, and the thickness of insulation is doubled for the wall and the roof with the installation of the same but new insulation material.

Impact of climate change and ageing

After individually considering the effects of climate and building ageing on the energy performance of the building, it is logical to progress on to a combined study that will more realistically simulate future evolution of the building. To simulate this, the conditions imposed in the previous two sections will be combined, that is, climate warming scenario A2 (table 1) and components degradation (table 2). The 2040 retrofit applied in the building ageing study will be maintained in this analysis.

RESULTS

Climate change simulations

The heating and cooling final energy usage results, for both scenarios A2 and B1, are shown in figure 1. The Torino building has an energy consumption that is dominated by the heating regime: fuel heating is the greatest energy consumer in the building. As the climate warms, the heating demand falls; the cooling load naturally increases due to the increased average temperature but the reduced heating consumption has the greatest impact overall. This building is overshadowed on three sides by high-sided buildings so solar gain is not very significant. Despite this, the ambient temperature increase warms the building sufficiently that heating energy demand is reduced significantly. Although the reduction in the heating energy usage outweighs the increase in electrical cooling usage, it should be noted that this might not be the case for the primary energy requirements for heating and cooling. Primary energy takes into account the extraction of the energy carrier (energy carrier being the form in which the energy is delivered, for example, electricity) and its transport to the utilization site, as well as processing, storage, generation, transmission, distribution, and delivery. As primary energy is typically higher for electricity than for natural gas (Molenbroek et al. 2011), this should be considered when estimating the overall impact on the total energy production required by the building. The present study, however, focuses solely on the variations of the on-site final energy usage of the building for heating and cooling.
The differences between the A2 and B1 warming scenarios were not very marked except beyond 2050. This is due to the IPCC predictions for the two climate scenarios having very similar temperature increases up to about 2050, after which they tend to diverge (see Bernstein et al., 2007 and table 1).
The effect of the heat wave is interesting because it shows an annual cooling demand that is 23% greater than the one obtained for the other scenarios, due to the extended warm temperatures. Due to the serious impact on energy consumption, with a predicted increase in extreme event occurrence, planners and engineers must seriously consider the possible measures that can be implemented to mitigate the worst effects of climate change.

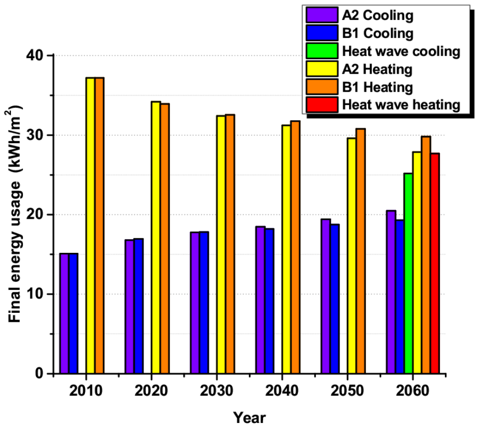

Figure 1. Cooling and heating final energy usage for the Torino building for scenarios A2, B1 and the heat wave. Simulations were run from present (2010) to 2060 in decadal steps.

This study is consistent with the findings of other investigations (Eskeland and Mideksa, 2010) concluding that cooler climates (higher latitudes) gain from climate warming in the form of heating energy usage reductions, outweighing the increase in cooling energy usage. However, the effect of climate change on buildings will be influenced by not only the latitude and altitude but also a more complex interplay of local temperature and humidity, building design, orientation, floor plan, height and shading, window size and number, required comfort levels, etc. The quality of the building material, such as insulation and glazing, and also the efficiency of technical facilities, will be a major issue in the mitigation of the effects of climate change.

Building ageing simulations

For simulating the ageing of the building, each parameter of table 2 is evaluated individually. The first simulation, year 2010, is conducted with the baseline-building model. The total annual energy consumption of this baseline is 120.1 kWh/m². The energy breakdown for the building at the reference year is presented in table 3.

For each ageing parameter, five new simulations were conducted in order to see the impact of this parameter alone, with all the other parameters set to the reference year value. This way, a total of twenty five simulations were conducted individually for the five parameters. Then five last simulations were done, one for each year with all the parameters changed altogether. The energy performance of the building should decrease for the first two simulations (years 2010 and 2020) then improve after the retrofitting (year 2040) and decrease again for the last two simulations (Year 2040 and 2050).

	Lighting	Electric cooling	HVAC Aux	Humidification
Year 2010 (kWh/m²)	10.7	15.4	5.1	21.5
	DHW	HVAC Fans	Fuel Heating	Equipment
Year 2010 (kWh/m²)	4.4	21.2	37.4	4.3

Table 3. Breakdown of the total energy consumption of the baseline building at baseline year (2010).

Figure 2 presents the evolution of the energy consumption of the building models compared to the one of baseline year for all the ageing parameters simulations described before. The two ageing parameters which have the greatest impact on the energy consumption of the building are the efficiency of the boiler and of the chiller. This is to be expected as HVAC equipment is very important in terms of energy usage but it slightly differs from the results of the sensitivity study where the two predominant parameters were found to be the external wall U-value and heat emission from appliances. This is due to the range of the evolution of each parameter, which is different in the parametric sensitivity study. These two studies are looking at the same parameters but in a different way. The sensitivity study looked at the uncertainties of definition of the values of some parameters while the ageing study looks at the variation in time of these parameters. It is therefore normal that the range of evolution is different even if the same parameters are under study.

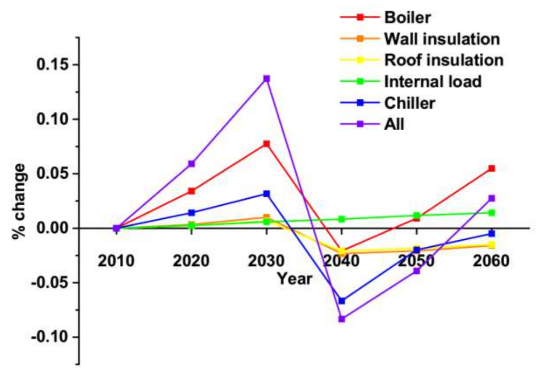

Figure 2. Evolution of the total energy consumption of the building for different ageing parameters by decade.

The impact of replacing the boiler and chiller at year 2040 is very important as this allows decreasing the energy consumption of the building by almost 20% which corresponds to about 25 kWh/m². In this context, with already more than 5 cm of insulation in the walls and the roof, the heating and cooling equipments are predominant. Figure 2 also shows that the other ageing parameters have a limited

impact on the total energy consumption of the building with a trend of less than 1% increase energy consumption every 10 years.
When looking exclusively at the energy consumption for heating and cooling (Figure 3), the impact of the retrofit is larger on the heating than on the cooling because the energy consumption of the library is largely due to its heating. Except for year 2040 when there is a retrofit, the energy consumption for both heating and cooling increases approximately in a 10% every 10 years, showing the importance of an up-to-date HVAC system in a building.

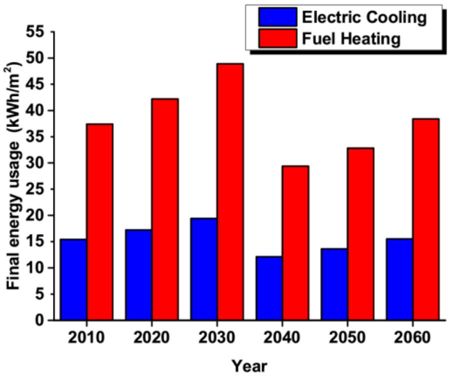

Figure 3. Effect of building ageing and retrofit on yearly final energy consumption.

Climate change and ageing simulations

The combination of ageing parameters and the effect of climate change are shown in the simulation results of figure 4. The comparison between climate effect only and climate effect plus ageing is shown from years 2010 to 2060. A building retrofit is also considered in 2040. From 2010 to 2030 the reduction of the heating energy consumption due to climate warming is overridden by the heating energy demand increase induced by building ageing, particularly due to the loss in boiler efficiency, which is seen as a resulting increase in the heating energy usage when both warming and ageing are considered together. Analogously, in the case of cooling, the increase of energy usage induced by warming is further increased, particularly due to the chiller efficiency loss.

A noticeable aspect is that while the warming climate scenario causes a modest overall energy decrease over the years, the ageing effect leads to a rising energy usage. The benefit of a retrofit, after 2030, is quite evident; the energy budget for heating and cooling are reduced by about 20% as a result. The percent variation of cooling energy usage with respect to the baseline case is shown in Figure 5. The results show that building ageing enhances the increase in the cooling energy consumption induced by climate warming, leading to an increase of about 50% of the energy with respect to the baseline year. The retrofit is seen as a critical measure to reduce the building energy consumption after 2030. Notice that there is a negative variation of the energy consumption for the ageing case, since retrofit implies achieving better conditions that the initial building state in 2010. Eventually as the building ages and the climate gets warmer the cooling energy consumption mounts up to 32% by 2060 with respect to the baseline.

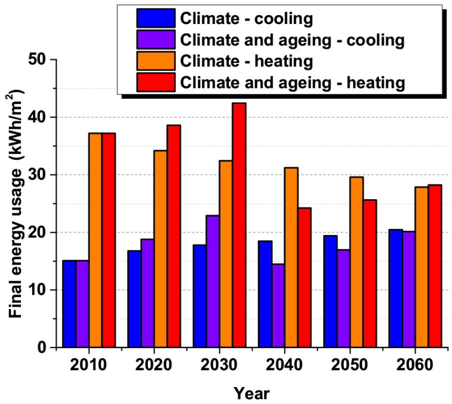

Figure 4. Final heating and cooling building energy usage under climate scenario A2 for the cases of climate change without ageing and climate change plus ageing. The building is retrofitted in year 2040.

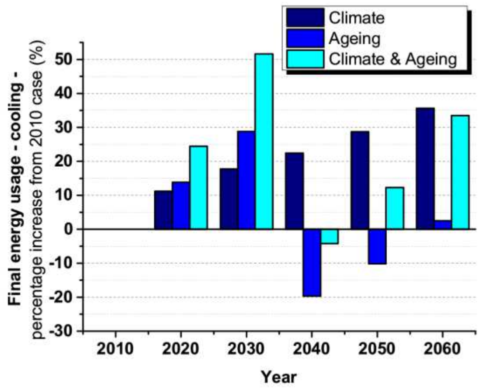

Figure 5. Percent variation of cooling energy usage with respect to baseline year.

Regarding the heating energy usage, figure 6 shows that from 2010 to 2030 it will eventually result in 30% higher consumption in a non-warming climate scenario, which is counteracted by the reduction of heating requirements due to climate warming down to 12.5%. The value of doing a retrofit after 2030 can been seen by the sharp reduction in heating consumption, with a potentially almost 20% reduction compared to 2010 with retrofit alone and up to 35% reduction if including predicted climate change. Because the retrofit improves the building performance with respect to the initial conditions a 20% reduction of heating energy is obtained in 2060 with respect to the baseline.

It has been shown that while climate change will have a significant impact on the energy profile of buildings in the near future, the building state is highly influential and should be considered in the building energy performance future projection. Studies based only on the effect of climate warming on the building energy demand in the future might produce biased conclusions if building ageing is also not considered in the analysis. Without well maintained infrastructure and components, such as the HVAC and insulation, there will be a marked increase in the energy consumption as the building ages, and this should be corrected with appropriate measures.

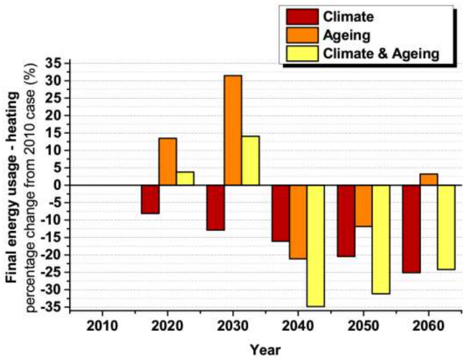

Figure 6. Percent variation of heating energy consumption with respect to baseline year.

DISCUSSION AND CONCLUSIONS

This study has presented a threefold approach to modelling building energy efficiency in the near future. The effect of predicted climate change effects has been investigated on a current building in Torino, Italy. Using forecasted model data from the IPCC synthetic scenarios report, a predicted temperature evolution has been applied to the model of the building and yearly simulations run for these higher future temperatures. The predicted climate warming produced an expected increase in the cooling load of the building with a percentage increase of about 35% from 2010 to 2060. As the ambient temperatures increase the final heating energy usage decreased in a percentage of 25% in the studied time window. Although the reduction in the heating energy usage outweighs the increase in the cooling energy used by the building in a warming climate, further analysis on the primary energy usage should be done to understand the implications of this variation in the environmental context. During the extreme heat wave event of the summer, where average temperatures were increased by 6 °C, the final cooling energy usage increased by 23%. This shows the potential burden that extreme events may place on world energy usage. In this study a 5% decadal increase of solar radiation was adopted for the climate change simulations. There is still high uncertainty in the prediction of the variation of solar radiation and its dependence of local conditions with climate change. Although the building energy calculations were low sensitive to this parameter, future work should include a more accurate prediction of this parameter.

Regarding the ageing study, the envelope components have a limited influence as explained in the results section. However, other envelope parameters could have a greater influence on the energy consumption of the building but are difficult to measure and be modelled, such as thermal bridges and air-infiltrations. This is especially the case for an old building to be retrofitted where data to model the actual state of the building are difficult to find. Even if the envelope of the building does not seem to be so important in our case study, a broader but more difficult approach using precise and true values of thermal bridges and air-infiltration may change the relative importance of the envelope. The study was conducted under the assumption that the usage of the building would be constant for the next 50 years. However, an increase of the number of occupants in the library may change greatly the results of this study. With more occupants, the requirements for air-renewal would increase throughout the year, and the air-conditioning system would be more important during the summer. Under such circumstances, the control of the HVAC systems would be very important to adapt the building response to this new occupancy, and a new sizing may lead to a change the whole system. The building under study is very particular because its energy consumption in order to maintain the desired relative humidity is very high, with 21.5 kWh/m² -more than cooling- for the baseline case at baseline year. It is difficult to model precisely an ageing of the humidifier with a decrease of its efficiency in the building model. However, a further step for this study could improve the modelling of the humidifier in order to allow a better building ageing analysis.

Combining the climate change and ageing provided a more realistic insight into the evolution of a real building. This also allowed us to see the relative weight of each process and how it affected the building and over what timescale. The simulations showed a prevalence of building ageing and retrofit on the energy profile of the building, in particular regarding the HVAC systems, which led to an increase of energy consumption over time. In the cooling regime there is the additional negative effect of climate warming, which together led to an almost 50% increase in cooling consumption from 2010 to 2030. Regarding heating energy consumption, the increasing energy demand due to ageing overrides the reduction in heating requirements produced by warming temperatures, which leads to an increase in the heating total energy consumption of the building in time. The results from this study also suggest that overall ageing and component efficiency should be considered as an important aspect in the change of building energy performance with time. This study indicates that proper maintenance of the infrastructure and components, and possible retrofitting, is vital for the efficient and comfortable running of the building in a future warming climate.

The expected negative influence of both building ageing and climate warming require improvements in building components and usage. Mitigation measures to limit the undesirable effects showed in this study should be considered to limit these effects. Different measures such as insulation, thermal mass, solar shading, night ventilation, indoor design condition and internal loads are potential practical techniques to apply to improve building performance to face climate warming and ageing. The efficiency of these measures, either individually or in varying combinations, should be investigated and tested for each building particular case and climate conditions.

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NOMENCLATURE

HVAC – Heating, Ventilation and Air Conditioning.
IPCC - Intergovernmental Panel on Climate Change.
JJA – Summer months of, June, July and August.
EPS- Expanded Polystyrene
XPS- Extruded Polystyrene

REFERENCES

Aebischer, B., Catenazzi, G., Henderson, G., and Jakob, M. 2007. Impact of climate change on thermal comfort, heating and cooling energy demand in europe. In *Proceedings ECEEE*, pages 859–870.

ASHRAE Handbook: HVAC Applications, 2015. Chapter 37. Owning and Operating Costs.

Bannai, M., Yoshida T., Kimura Y., Fujii, T., Sekiguchi, K., Sawa T. 2008. Energy Solution in the Industrial and Commercial Sectors. Hitachi Review Vol. 57 No. 5.

Beniston, M. 2004. The 2003 heat wave in europe: A shape of things to come? an analysis based on swiss climatological data and model simulations. *Geophysical Research Letters*, 31.2.

Bernstein, L., Bosch, P., Canziani, O., Chen, Z., Christ, R., and Davidson, O. 2007. Climate change 2007: synthesis report. summary for policymakers. In *Climate change 2007: synthesis report. Summary for policymakers*. IPCC.

Elsland, R.; Peksen, I.; Wietschel, M. 2014. Are internal heat gains underestimated in thermal performance evaluation of buildings?, Energy Procedia, Karlsruhe.

Eskeland, G. S. and Mideksa, T. K. 2010. Electricity demand in a changing climate. *Mitigation and Adaptation Strategies for Global Change*,15(8):877-897.

Insulfoam technical center. 15 year performance of below-grade insulation- EPS & XPS Insulfoam Technical Bulletin, no. 1022.

Kehrer, M. and Christian, J. 2012. Measurement of Exterior Foundation Insulation to Assess Durability in Energy-Saving Performance. Oak Ridge National laboratory report. ORNL/TM-2012/159

Molenbroek, E., Stricker, E., and Boermans, T. 2011. Primary energy factors for electricity in buildings - toward a flexible electricity supply.

Pilli-Sihvola, K., Aatola, P., Ollikainen, M., and Tuomenvirta, H. 2010. Climate change and electricity consumption - witnessing increasing or decreasing use and costs? *Energy Policy*, 38(5):2409–24.

Santamouris M., Cartalis C., Synnefa A., Kolokotsa, D., 2015. On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review. Energy and Buildings, *in press*.

Pasi, S., Muller, M. R, Investigating the Impact of Boiler Aging In Replacement Decisions, Tech. Rep., Rudger University – Center for Advanced Energy Systems, 2007. ACEEE Summer Study on Energy Efficiency in Industry.

Wan, K. K. , Li, D. H., Pan, W. Lam, J. C. 2012 Impact of climate change on building energy use in different climate zonesand mitigation and adaptation implications, Applied Energy 97, 274–282.