Impact of climate change on Pakistan’s building thermal energy needs and comfort conditions

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Impact of climate change on Pakistan's building thermal energy needs and comfort conditions

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ABSTRACT

Global warming is increasing average air temperature, affecting energy consumption and thermal comfort inside buildings. This study investigates the relative impact of climate change on thermal energy needs and indoor thermal comfort conditions for a typical residential building located in different climates of Pakistan. Furthermore, the energy-saving potential and thermal comfort performance of various traditional and advanced retrofit measures are evaluated to mitigate the impact of climate change. Climate Change World Weather File Generator was used to produce weather files of typical metrological years of 2020, 2050, and 2080 under emission scenario A2 of the Intergovernmental Panel on Climate Change (IPCC). TRNSYS simulation software and ASHRAE adaptive discomfort model were used to calculate annual thermal energy demand and comfort conditions inside the buildings. The impact of climate is city-specific. Overall, results show that the temperature will increase in the range of 0.9-1.4 °C and 2.3-3.7 °C for the year 2050 and 2080 respectively from the present level (2020) while the absolute humidity increase range is 0.2-1.3 and 0.3 to 3.3 g/kg of air for the same years in the investigated cities of Pakistan. This would result in higher thermal energy needs for cooling in the range of 9.7-28.4 kWh/m^2 by 2050 and 28.4-49.9 kWh/m^2 by 2080. The climate-responsive retrofit solutions should be promoted by authorities and policymakers to strengthen a climate-resilient pathway of building stock in Pakistan.

Keywords: future weather files, adaptive comfort model, climate change, Pakistan, TRNSYS, mitigation strategies

1. INTRODUCTION

The building sector is the highest primary energy consumer in the world, accounting for nearly 40% of energy and is also responsible for 30% of energy-related greenhouse gas emissions [1]. Global warming is increasing average air temperature, affecting energy consumption and thermal comfort inside buildings however, the impact of climate change is different in different parts of the world. According to IPCC 5th assessment report of climate change projections for South Asia shows that temperature increase in this region is higher than the average global mean and buildings in Pakistan are, therefore, likely to be adversely affected by any rise in temperature. Pakistan despite being responsible for only 0.8 % of global CO_2 emissions is among the top ten most affected countries from climate change in the last two decades.

The building sector in Pakistan consumes around 50% of all electricity, and more than 70% of this electricity comes from fossil fuel-based thermal power plants. The highest share of this electricity is used in heating, ventilation and air conditioning. Recently, Pakistan assured the world to shift to 60% clean energy. To mitigate the impact of global warming in Pakistan's cities and to reduce the amount of non-renewable energy consumption in the coming decades, it is imperative to investigate the impact of climate change on thermal energy requirements and comfort conditions inside buildings. In this regard, this paper

a) Investigates the current and future heating and cooling thermal energy needs in buildings in different climates of Pakistan.
b) Evaluate annual heat discomfort hours for a typical free-running residential building in

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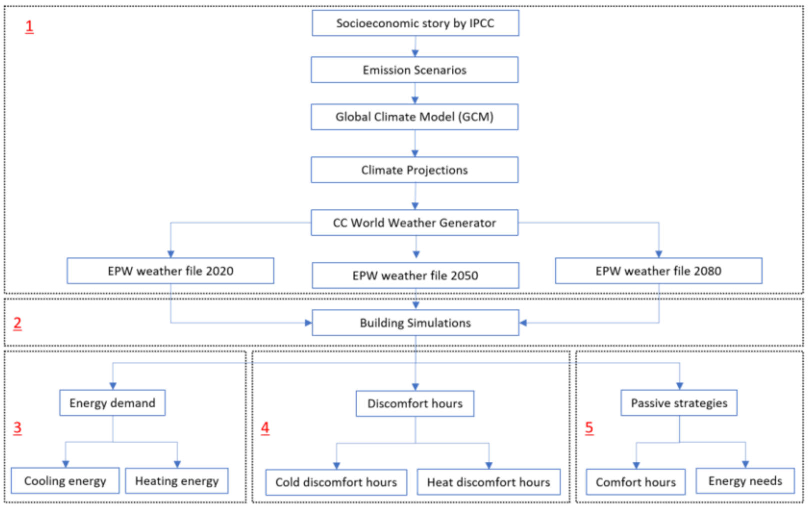
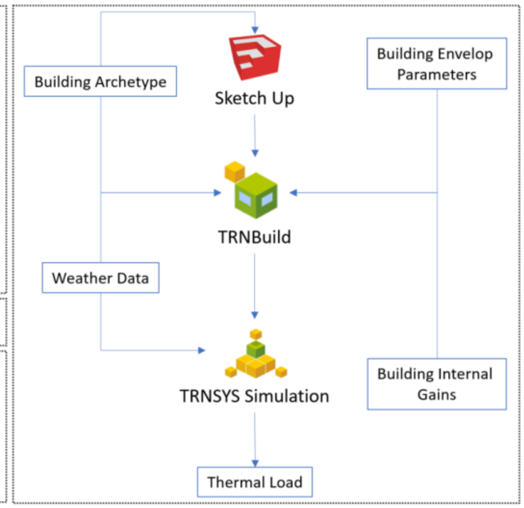
different regions of Pakistan to identify vulnerabilities and climate risks.

c) Investigates the role of different passive techniques to reduce annual discomfort hours and thermal energy demand to promote future building standards in existing buildings.

transforms original Energy Plus weather files to ''climate change'' weather files with ''morphing procedure'' using Energy Plus weather file and GCM model (HadCM3) that is representative of the future weather. Among the various climate models, HadCM3 has been widely used for predicting future climates [3]. Further details on the CCWorldWeatherGen can be found from [4].



(a)



(b)

Fig.1. (a) Study conceptual framework; (b) Flow diagram for simulation methodology

2. MATERIALS AND METHODS

The overall methodology employed in this work is shown in Fig. 1(a). The IPCC publishes a set of possible scenarios of future anthropogenic greenhouse gas emissions based on given socio-economic storylines. These emissions scenarios are used as an input to Global Climate Models (GCMs), which are the most complex quantitative models for forecasting climate change. GCMs simulate how the atmosphere, ocean, and land surface interact with each other and predict metrological parameters with monthly average values at coarse resolution (100-200 km). Regional Climate Models (RCM) are used to downscale this prediction at a resolution of 25 to 50 km. The 'morphing' technique in this case is used to add projected monthly changes to historical hourly weather files to generate future weather files. These projections are used to generate weather files for the building simulations. Different TRNSYS building simulations are run for 2020, 2050 and 2080 to calculate the energy demand, discomfort hours and the effects of different passive strategies.

2.1 Climate Data

To create future weather files for the current study, we used a tool named Climate Change World Weather File Generator (CCWorldWeatherGen) [2]. This tool

2.2 Numerical model for calculation of cooling and heating loads

The numerical model was developed in a simulation software called TRNSYS (Trnsys System Simulation) v18.2, widely used by researchers in the energy simulation community to model and simulate the transient behavior of energy systems. The TRNSYS model library has built-in components for the calculations of thermal loads, ventilation, and air conditioning systems as well data files, making it very suitable for the calculation of heating and cooling loads.

2.2.1 Building model and calibration

The selected building is a design of a two-story building typical for multifamily in Pakistan. The residential building contains two bedrooms, a living room, a kitchen, and two bathrooms on each floor and has a total floor area of 250 m^2. The flow diagram for simulation methodology is shown in Fig. 1(b). First, the building archetype is defined in SketchUp. The geometric model is then imported in TRNSYS TRNBuild v3.0 model to include building envelop characteristics (walls, windows, roof), internal gains (light, equipment, and occupants), and their variability over time. The main parameters of building fabric are shown in Table 1.

TRNBuild generates a "*.b18" file, which is used as an external file in TRNSYS Simulation Studio (Type56). In TRNSYS simulation studio, a typical weather file (EPW) of different cities of Pakistan generated from the CCWeatherGen tool, as described in section 2.1, was implemented using the standard weather data reader component (TYPE 15-3) for the calculation of thermal loads of respective city for the year 2020, 2050 and 2080. TRNSYS simulation studio reads and processes the input file (like weather file and *.b18 file generated from TRNBuild), before iteratively solving the system and plotting the system variables.

Table 1. Building envelop characteristics

Element	Definition	Characterization
Windows	Single glaze window with aluminum frames	U-value:5.72 W/m^2 K
Façade	Solid burnt clay bricks, cement mortar	U-value:2.19 W/m^2 K
Roof	Concrete, cement mortar, bitumen, mud Phuska, PCC, roof tiles	U-value:2.02 W/m^2 K
Floor	Soil, sand, brick masonry (clinker), plain cement concrete, ceramic tiles	U-value:0.77 W/m^2 K
Internal walls	Solid burnt clay bricks, cement mortar	U-value:2.92 W/m^2 K

Infiltration leakage is defined by an air change rate (ACH) of 1.2 per hour. Thermal bridges were considered at 0.1 W/m^{2}K of envelop area. To model the heat transfer from the floor to the soil, Type 77 (ground temperature model) was used. To control the cooling and heating operations, a control logic based on occupancy was defined. The building model was calibrated with monthly energy data using a reference case in Lahore. Gas and electricity bills were compared with simulation results through an iterative calibration process, in which uncertain parameters were adjusted until the model agreed with the measured data. Mean bias error between measured and simulation results based on electricity and gas bills were found as -0.73% and 0.42% respectively which is within the acceptable limit of ASHRAE criteria. Similarly, CV-RMSE values were also within acceptable limits such as 9.11% (for electricity) and 8.49% (for gas). The coefficient of determination (R^2) was calculated as 0.82 and 0.90 based on electricity and gas bills respectively compared to TRNSYS simulation results.

2.3 Thermal loads

Cooling load were calculated for considering thermostat settings of 25°C (night time) and 24°C (day time). The design humidity ratio was consider as 14 g/kg. The heat demand were calculated considering thermostat settings 21°C according to the guideline of the building code in Pakistan.

2.4 Discomfort hours calculations

This study used the adaptive comfort model ASHRAE 55-2017 to evaluate the impact of climate on free-running buildings. Cold discomfort hours (DHc) represent periods when the operative temperature remains lower than the temperature of comfort range defined by ASHRAE, while the heat discomfort hours (DHh) represent the number of hours in a year when the operative temperature lies above comfortable temperature.

$$\mathrm{D.H._c} = \sum_{1}^{t} \Delta t \quad \text{if Top} < 0.31\ f(\mathrm{T_{out}}) + 14.31 \qquad (1)$$

and

$$\mathrm{D.H._h} = \sum_{1}^{t} \Delta t \quad \text{if Top} > 0.31\ f(\mathrm{T_{out}}) + 21.31 \qquad (2)$$

where $f(T_{out})$ is the prevailing mean outdoor air temperature and is calculated according to guidelines from ASHRAE 55 [5].

2.5 Mitigation and adaptation measures

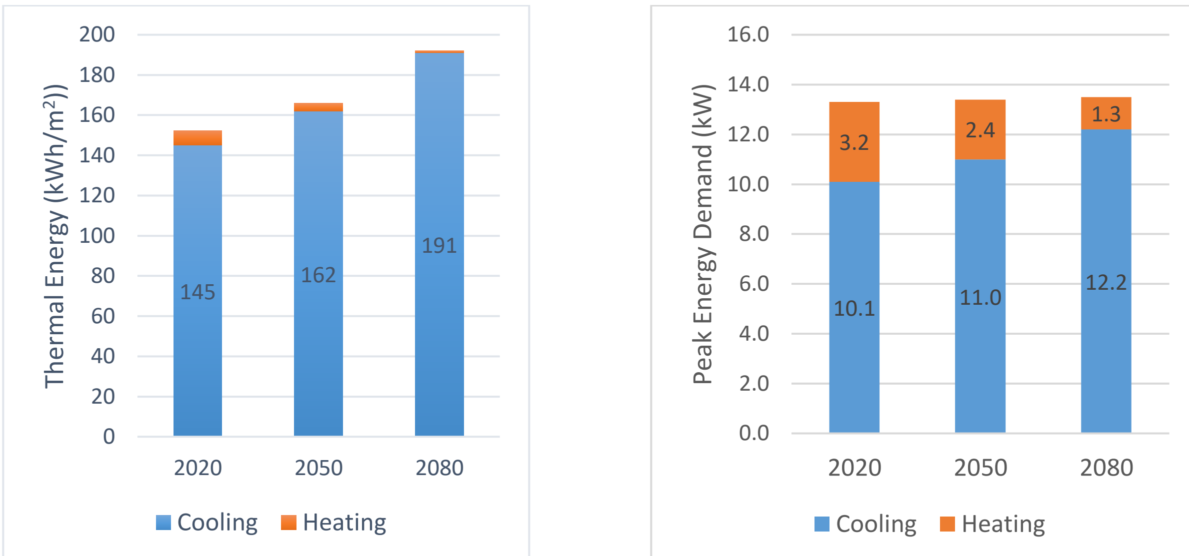
The design of buildings under changing climate to improve thermal comfort and reduce thermal loads is a challenging task. In this study, the following strategies are investigated: 1) window upgrade, 2) high thermal mass, 3) airtightness, 4) internal and external shading, 5) low absorptance of roof and facade.

3. RESULTS AND DISCUSSION

The impact of climate change on Pakistan's buildings thermal energy needs and comfort conditions are discussed in this section. First, the weather files of 2020, 2050 and 2080 were created using the methodology as described in section 2.1 for 39 cities of Pakistan. The weather file analysis shows that temperature is increasing for all cities, but it is city-specific. The results show that the temperature will increase in the range of 0.92-1.45 °C and 2.31-3.73°C for the year 2050 and 2080 respectively from the present level (2020), while the absolute humidity increase range is 0.25-1.35 and 0.35 to 3.34 g/kg of air for the same years in Pakistan. This increase in temperature and humidity ratio would result in higher thermal energy demand, as discussed in section 3.1.

3.1 *Thermal energy demand for cooling and heating*

The annual cooling and heating energy demand and peak cooling and heating energy demand for 2020, 2050, and 2080 for the city of Lahore are shown in Figure 2. It shows that both annual and peak cooling energy demand are increasing over the years while the annual heat and peak heating demand are decreasing. The total thermal energy demand for cooling increases from 145 kWh/m^2 (2020) to 162 kWh/m^2 by 2050 (12% increase) and to 191 kWh/m^2 by 2080 (32% increase) for Lahore. Similarly, this trend is reflected in maximum peak cooling load demand, where it increased from 10.1 kWh to 11.0 kWh by 2050 and 12.2 kWh by 2080. On the other hand, thermal energy requirements for heating decrease from 7 kWh/m^2 to 4 kWh/m^2 by 2050 and by 2080 there is almost no need of heating requirements for this city. Peak energy demand for heating also showed a downward trend. It decreased from 3.2 kWh to 2.4 kWh and 1.3 kWh by 2050 and 2080 respectively. Similarly, it is found that the length of the summer season (cooling system stayed on) is increasing while the winter season is shortening over the years. It is found that the operational hours of the cooling system in 2020 are 4625 hours, which are increased to 4883 and 5386 hours by 2050 and 2080, respectively. On the other hand, the number of hours for heating requirements are reduced from 716 hours in 2020 to 426 and 119 hours by 2050 and 2080, respectively.



(a) (b)

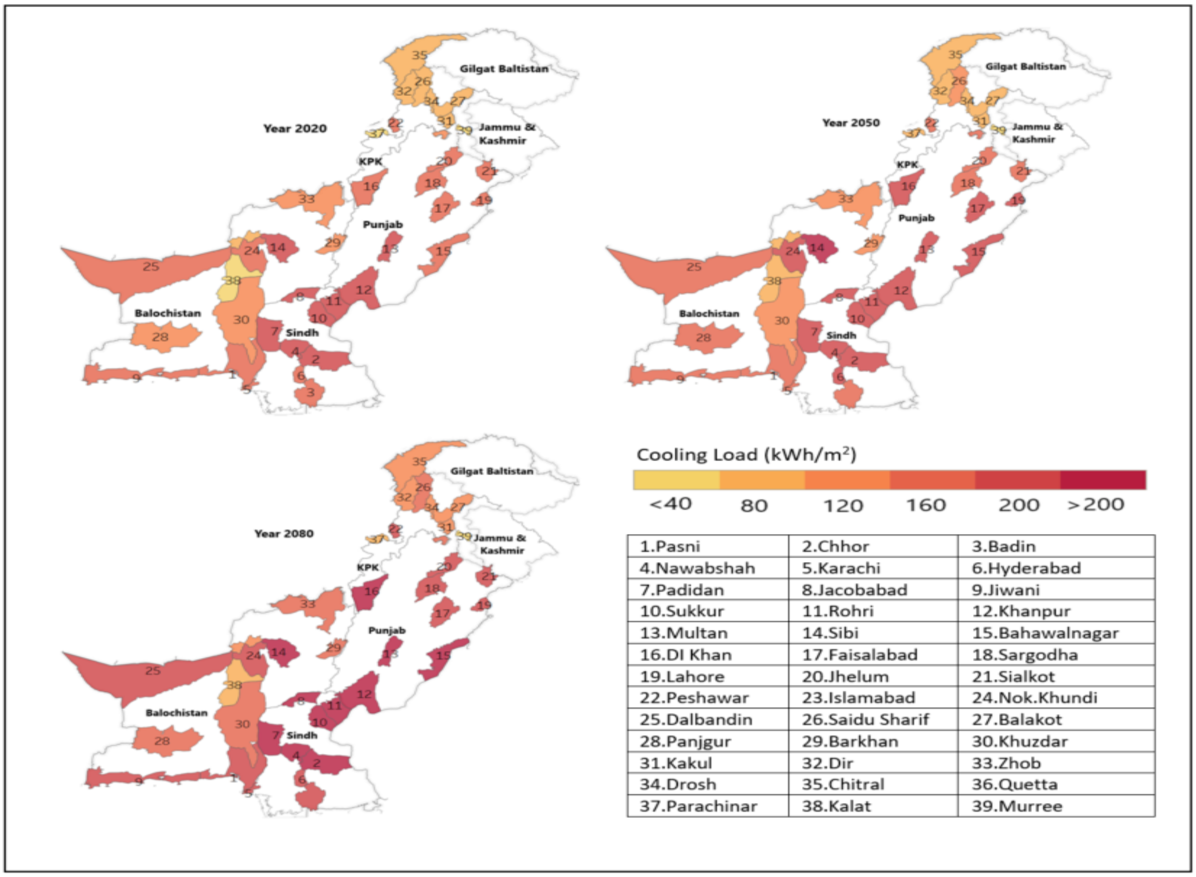
Fig.2. Thermal energy demand for cooling and heating (a) annual; (b) hourly peak

To investigate the relative impact of climate change on thermal energy needs for cooling and heating in different climates, the model was simulated for 39 cities of Pakistan assuming the same building fabric and internal gains. The results of thermal energy demand for cooling in 39 cities of Pakistan for 2020, 2050 and 2080 are shown in Fig.3.

Based on the hourly simulation results, maximum cooling energy requirements from 39 investigated cities were found in Sibi (194 kWh/m2) in Balochistan for 2020. This cooling energy demand under the climate change scenario of A2, is going to increase to 213 kWh/m^2 and 244 kWh/m^2 by 2050 and 2080 respectively. On the other hand, minimum thermal energy requirements for cooling were found in Murree (9 kWh/m^2) in 2020. The energy demand for cooling in this city is also going to increase to 18.8 (by 2050) and to 39.5 kWh/m^2 by 2080. The overall average cooling energy demand for the 39 cities is 119 kWh/m^2 in 2020 and this will increase to 162 kWh/m^2 (+36%) by 2080.

3.2 *Thermal comfort*

In this study, heat discomfort hours for 39 cities of Pakistan were calculated by considering free-running buildings to investigate the vulnerability of climate change. Results of only one city (Lahore) are shown in Fig. 4 due to space constraints. The results indicate that heat discomfort hours are increasing over the years. It is found that heat discomfort hours will increase from 4625 hours to 4883 by 2050 (+6%) and up to 5386 hours by



1.Pasni	2.Chhor	3.Badin
4.Nawabshah	5.Karachi	6.Hyderabad
7.Padidan	8.Jacobabad	9.Jiwani
10.Sukkur	11.Rohri	12.Khanpur
13.Multan	14.Sibi	15.Bahawalnagar
16.DI Khan	17.Faisalabad	18.Sargodha
19.Lahore	20.Jhelum	21.Sialkot
22.Peshawar	23.Islamabad	24.Nok.Khundi
25.Dalbandin	26.Saidu Sharif	27.Balakot
28.Panjgur	29.Barkhan	30.Khuzdar
31.Kakul	32.Dir	33.Zhob
34.Drosh	35.Chitral	36.Quetta
37.Parachinar	38.Kalat	39.Murree

Fig.3. Thermal energy demand of cooling for different cities of Pakistan in 2020,2050 and 2080

2080 (+16%). These results demonstrate the need to consider different passive techniques to mitigate the effect of climate change on thermal comfort hours on residential building stock.

3.3 *Mitigation strategies*

In this study, different types of retrofit measures such as windows upgrade, high thermal mass, airtightness improvements, internal and external window shading, night ventilation and low solar absorptance for roof and faced are investigated. Parametric results of different traditional and advanced retrofit measures are shown in Fig.5. It is found that thermostat settings, roof insulation, wall insulation and solar absorptance of roof have significant potential to reduce the energy needs for cooling. Overall, it is found that all passive solutions reduce the thermal energy demand and increase the building energy performance. However, to find out the optimal combination of retrofit measures in different climate zones for free-running and air conditioned building is a challenging task. Results of this will be reported in future publications.

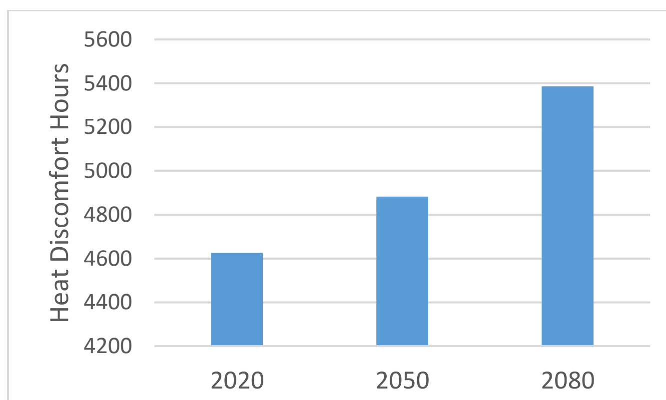


Fig. 4. Heat discomfort hours for 2020, 2050 and 2080

4. CONCLUSIONS

This paper is the first to systematically investigate the impact of climate change on cooling, heating and thermal comfort conditions inside residential buildings in distinctive climates of Pakistan. The results show that the impact of climate change varied greatly among different cities. The average cooling energy demand of all investigated cities from 2020 to 2080 is increasing by 36%, while heat demand will decrease by 68%. Cities located at lower elevations in Pakistan have higher heat discomfort hours, while cities with higher elevations have higher cold discomfort hours in free-running buildings. Under changing climate, an optimal combination of traditional and advanced passive techniques can reduce annual thermal energy demand and total discomfort hours.

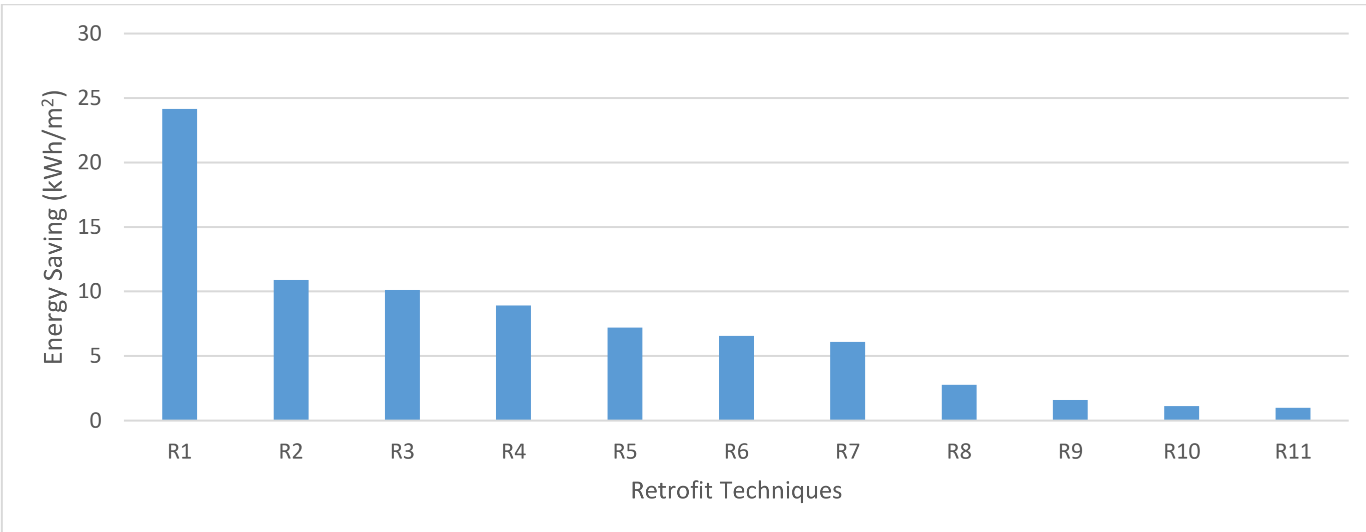


Fig.5. Effects of retrofitting techniques on thermal energy demand for cooling

Table 2. Traditional and advanced retrofit measures

Code	Description	Base Case	Retrofit
R1	Set-point temperature	Day: 24ºC, Night:25ºC	Day: 26ºC, Night:27 ºC
R2	Insulation of exterior walls	2.19 W/m^2.K	0.8 W/m^2.K
R3	Solar absorptance of roof	0.65	0.25
R4	Insulation of roof	2.02 W/m^2.K	0.44 W/m^2.K
R5	Solar absorptance of exterior walls	0.5	0.25
R6	Air tightness	1.2 ACH	0.6 ACH
R7	External shading of windows	SRF: 0.2	SRF: 0.6
R8	Replacement of window	5.72 W/m^2·K	2.29 W/m^2·K
R9	Heat flow rate of appliances	3.0 W/m^2	2.4 W/m^2
R10	Default allowance per envelope area	0.10 W/m^{2}K	0.05 W/m^{2}K
R11	Heat flow rate of lighting	2.0 W/m^2	1.6 W/m^2

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