Passive Cooling Design Strategies for Retrofit of Residential Tower Blocks in Northern Cyprus

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Abstract: This research investigates potential passive design strategies for improving the thermal performance of existing residential tower block (RTB) in Famagusta, Northern Cyprus. In a Mediterranean island that experiences hot and humid temperatures throughout the year, residential buildings need to be adaptable to the climate in order to improve the thermal comfort of occupants. The current housing stock includes a prevalence of high density, medium and low-rise residential tower block developments without implementing any insulation materials. The objective of this study is to develop and test passive cooling design strategies into retrofitting ill-performing residential tower blocks in the coastal city of Famagusta. As an initial step, the performance of a case study was modelled and simulated via employing Integrated Environmental Solutions - Virtual Environment (IES-VE) software add-ins Apache-Sim Dynamic Thermal Simulation. The results from the base case model were analyzed according to the adaptive comfort of CIBSE Technical Memorandum 52 guidelines: The Limits of Thermal Comfort – Avoiding Overheating in European Buildings. The spaces studied (living room and bedrooms) within the case study sample flats were observed to exceed the acceptable limits of thermal comfort; particularly living rooms with this zone exceeding the upper limit for overheating by up to 9 hours daily. The main reasons for the problematic thermal performance were identified as resulting from: infiltration through the building fabric, the lack of sufficient ventilation through the living spaces and excessive heat gains through the large areas of glazing. The internal operating temperatures of the simulated flats remain high throughout the day and night in a typical summer day, ranging from a maximum of 36.5°C to a minimum of 28.5°C. The study also analyses the effectiveness of two basic passive cooling strategies (shading and night ventilation) of 3 sample flats sharing the same orientation, and floor plan but located at different levels within the RTBs. Furthermore, the implications in the seasonal cooling and assessment when considering the adoption of climate-related set-point temperatures (i.e. adaptive comfort approach), beyond the assumed common standard, are also evaluated.

Keywords: Building energy performance, Overheating, Passive cooling strategies, Thermal comfort, Retrofit.

Introduction

The residential building stock represents 30% of the existing building stock in the Turkish Republic of Northern Cyprus (TRNC) (The Department of Social Housing-TRNC (Sosyal Konut Mudurlugu in Turkish) (2015). Problems in mass housing estates in TRNC have been an issue for research with regards to energy policy interventions for many years (ibid). High density of the residential tower block developments and soaring land value in the Mediterranean city of Famagusta have driven residents to maximise liveable spaces by modifying their properties. Simultaneously, as a result of fast rise in population growth and un-planned urbanisation associated with the high-land value and increase in energy consumption leads to the significance of this research in energy efficient retrofit. Studies from the Association of Cyprus Turkish Building Contractors (Kibris Turk Insaat Muteahhitleri Birligi in Turkish) (2016) highlight that strategic consideration for retrofitting the residential building stock would therefore help achieve significant energy efficiency targets. However, the construction industry lacks strong drivers to implement energy efficient technologies through building construction and retrofit. It is important to note that in this research context, air-conditioning (A/C) units running with electricity are mostly being used for cooling. The Electricity Authority of the TRNC (KIB-TEK - Kibris Turk Elektrik Kurumu in Turkish) in 2016 indicates that residential sector cooling energy use was consumed on 230.367 Mk/Wh in 2003 and this figure rose to 377.971 Mk/Wh in 2015. Given this challenging context, reducing energy consumption of residential buildings particularly in cooling demand can be considered as crucial. The focus of this paper is to investigate the most effective and feasible passive cooling design strategies into retrofitting for energy efficiency and improved indoor thermal comfort.

In this study, an exploratory case study approach is adopted in Famagusta where an existing prototype RTB is explored and analysed according to overheating benchmarks applied on a sample of flats to understand the cooling demand as related to occupants' thermal comfort. This paper is structured as follows; the paper will first discuss the background and justification of research, followed by the hypothesised relationship with regard to the relevant literature. This is then continued with explanations on the methodology employed. Preliminary findings and discussions are given prior to the conclusion.

Background and Justification of Research

Location and Climate

Cyprus, is the third largest island after Sicily and Sardinia. It is located in the Eastern part of the Mediterranean, at latitude 35° North and longitude 33°. According to the Köppen Geiger climate classification, Cyprus has climate characteristics that are typically Mediterranean. The hot and humid summers and wet moderate winters are the main climate characteristics and cause some problems in terms of the demands on energy consumption, because of the requirement for a combination of summer cooling and winter heating. Hence, it also serves to highlight the fact that the prevailing south-west winds are change the relative humidity rate up to 90% along the south coast line in summertime, especially during evening hours. Indeed, it is possible to go so far to as say that this situation affects the thermal comfort conditions of buildings and severely increases the demand for space cooling.

Thermal comfort approaches and Building performance

Many field studies have been conducted in various climates across the world which demonstrate that comfort temperature is closely linked to local climate (Brager & de Dear 1998; McCartney & Nicol 2002; Nicol 2017; Taleghani et al. 2013; Zhang et al. 2017). By following a similar approach, the adaptive thermal comfort theory explains this phenomenon with respect to occupants' active engagement with their indoor environment (de Dear & Brager 1998; Nicol et al. 2012). According to a study by Nicol and colleagues, starting from 2002, an alternative approach to defining comfortable temperatures is the adaptive approach, which stems from the results of a wide range of field studies (McCartney & Nicol, 2002; Nicol & Humphreys, 2002 and Nicol, 2017). From this study, it was found that the thermal expectations of the occupants are related to the outside climatic conditions on a variable basis.

However, it is important to note that there is little information about night-time thermal comfort (CIBSE, 2013). Studies have also shown that sleep deprivation due to overheating during the night is a major motivation for buying domestic cooling appliances. Apart from the most energy efficient building systems and applications, the conventional passive cooling strategies involve shading the transparent elements of the building envelope and ventilating the spaces effectively during the night-time (Santamouris, 2007). Ferrari et al. (2009) and Zanaotto et al. (2009) studies emphasised the possible implementation of a night cooling strategy during the summer season would have a greater impact on cooling demand when performing dynamic analysis. Studies have also shown the lower air temperature is related to the high daily air-change rate in the monthly average (ibid).

The simulation studies by Ferrari and Zanaotto et al. (2010) asserted that the substitution of the standard set-point with the daily air-change rate could result in a decrease in the discomfort degree-hours calculation. Although not specifically exploring retrofit options, some other studies provide useful references regarding the important role of programmed natural ventilation which can reduce the risk of overheating experienced in RTBs in London (Zahari and Elsharkawy, 2017). Apart from that, starting from these base case studies, cooling demand varies between 10% and 50%, depending on the building orientation and the level of implementation of passive cooling strategies in Famagusta (Ozarisoy and Elsharkawy, 2017). These studies show evidence that the increase of energy consumption related to active cooling of building is a serious environmental danger, and so it is important to increase the number of residential buildings entirely or at least partially relying on passive cooling strategies. However, it should be emphasised that the adaptive comfort standards are a very important mean (Gossauer and Wagner, 2007), which could be adopted in retrofit strategies.

This trend is particularly problematic in the urban context where there is less air movement and urban heat island effects are most noticeable after dusk (Antarikananda et al. 2006; Santamouris et al. 2007 and Suenderman 2015). Consequently, in urban areas of Famagusta, the adoption of globalised housing design standards and inadequate standards for thermal comfort assessment in RTB development projects means that affordable RTBs are planned and designed without climatic considerations resulting in relatively high indoor air temperatures and reduced thermal comfort.

The adaptive approach concerning thermal comfort is currently implemented in the main international standards (EN 1521 2007; ASHRAE 2004). However, the CIBSE Overheating Task Force decided that a new approach to the definition of overheating is necessary, particularly residential buildings without mechanical cooling. This approach follows the methodology and recommendations of BS EN 1521 (BSI, 2007) to determine whether an existing occupied building or a proposed building can be at risk of overheating. Within Famagusta and its urban agglomerations, studies have shown the fact that many RTBs in TRNC currently struggle with overheating and this trend will only become worse with climate change (Ozarisoy & Elsharkawy, 2017).

Research Methodology

Case study: Prototype residential tower block (RTB) as a base case scenario

The case study for this research is an RTB estate which was designed in 2009 and completed in 2011 (Figure 1 and Figure 2). It is fully managed by a privately-owned construction company and all flats are exclusive when constructed; having lifts, central heating installation and double-glazed windows. It comprises 200 flats over nine 11, 12 & 14 storey towers. In this case study buildings, the existing status shows obvious deterioration of the building envelope, as cracks in the upper floors, damaged concrete balconies, visible signs of moisture in the areas suffering thermal bridges. It is also remarkable to note that there are too many external units for the split-unit air conditioning systems. Even with its specificities, the prototype RTB can be considered as representative of other RTBs in the estate.

(a) (b) (c)

Figure 1. The current condition of the prototype residential tower block development and the south west facing tower block.

(a) (b)

Figure 2. The floor plan layout of the prototype residential tower block development and flat type A.

Research design model

To provide sufficient understanding and analysis of indoor thermal comfort, it was deemed necessary to use a dynamic thermal simulation (DTS) model. The Integrated Environmental Solutions-Virtual Environment (IES-VE) suite was selected as the most appropriate application for this purpose. In terms of validated performance, IES-VE is understood to meet a number of international standards including CIBSE TM 52 and is also accredited for use to European standard BN EN 1521 (IES, 2017).

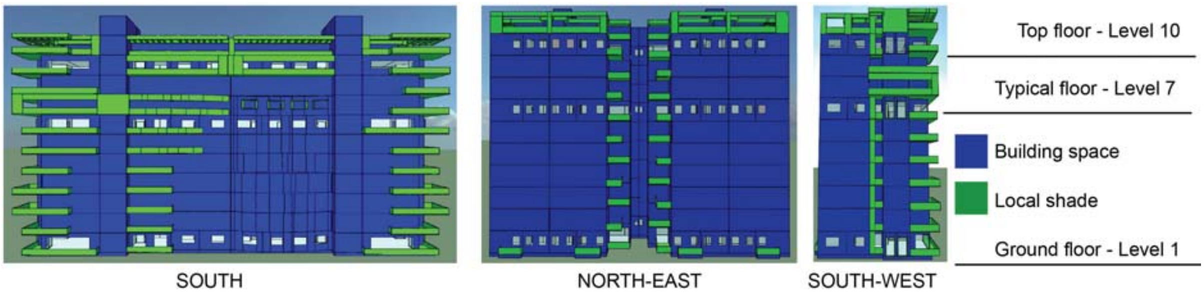
The IES-VE version used throughout was IES-VE 2017.1.0.0. Specifically, the Thermal Comfort add-ins of the IES-VE suite was found to be an application that could offer to measure the 'adaptive comfort' of a prototype RTB. It is also of interest to consider in combination with the Dynamic Thermal Simulation (DTS) components of the IES-VE. The model was set up in order to assess the performance of the dwelling under the "worst case scenario" conditions for the south-west facing case study RTB. In this study, profiles were set in the IES-VE application as required for each zone to describe temporal variation in the following: ventilation flow rates, cooling set-point, lighting use and occupancy profiles. Table 1 shows the summary of conditions set up for the base-case model. The performance of the base-case model has been studied with a focus on the risk of overheating.

Table 1: Summary of conditions specified for base case model analysis using IES-VE.

Specified Condition	Base-case Model Settings
Simulation Period	1st May – 30th September
Weather Data	Larnaca, Cyprus
Occupants	4 occupants with internal gains of 90W/person/day
Occupancy Patterns	20:00-6:00 working days, occupied all other times
Internal Gains	Gas cooking stove 106 W/m^2, lighting 8W/m^2

Building geometry

The case study RTB is characterised by a rectangular plan (40mx15m) and consists of 11 floors. The ground floor areas are occupied by conditioned spaces (i.e. dwelling units or technical rooms) in order to neglect the variability due to the thermal exchanges to the basement, while all the 10 upper floors are divided into a central distribution space (unconditioned lift and staircases areas) and two side volumes, containing three different floor plan design flats; Type A, B & C as can be seen in Figure 3.



(a) (b) (c)

Figure 3. The analytical energy simulation model of the tested case study prototype residential tower block.

The rooms and their openings are located on the three different facing facades allowing to appreciate, through only three different plan designs per floor of the model. The performances of the three exposures cover the main orientation cases (North, South and South-West). The simulation outputs can be required also referring to the simulated room zones having the same exposure. Furthermore, the specific results (i.e. each square meter of floor) can be assumed, even in first analysis, for defining the performance of representative flats. Moreover, seven rooms were simulated and evaluated in detail, so that all the possible different performances due to the boundary conditions options were analysed: the first floor, typical floor and top floor south-west facing representative flats.

Building constructions

To define the building model set, by limiting the number of the variables, the internal structures remain constant – based on the traditional construction materials of the era, hollow brick walls and concrete slabs, while the horizontal envelope components have minor changes depending on the sample flat plan design of the RTB. Hence, the main variation regards the construction materials, building envelope, and involves a window percentage and a construction solution that are representative of likely practices from the newly built RTBs. For this purpose, the building envelope solutions (i.e. shading and ventilation) have been taken into account, with hollow bricks walls and a window surface equal to 1/8 of the floor area, which is a common construction code to provide natural ventilation and lighting. The horizontal components are simple un-insulated concrete and masonry elements. The thermal characteristics of all the considered constructions are summarised in Table 2.

Table 2: Thermal characteristics of the construction elements of the prototype RTB.

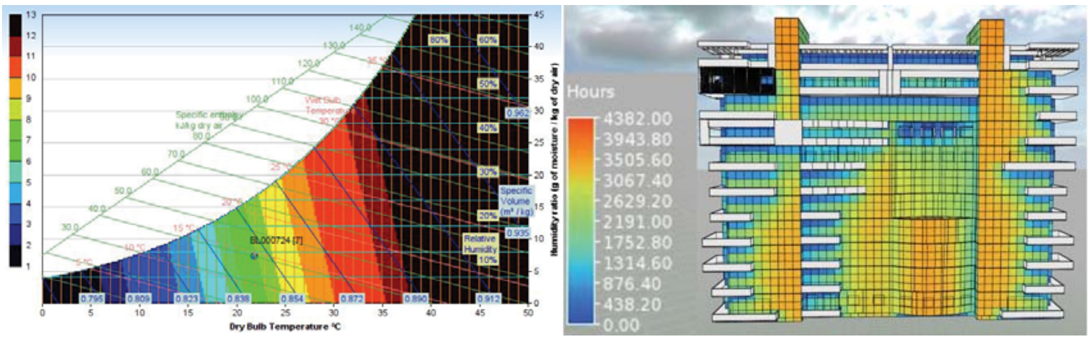
	S[cm]	U [W/(m^{2}K)]	M [kg/m2]	C [kJ/(m^{2}K)]
Vertical walls	35.00	0.98	305	264
Roof	36.00	0.91	317	302
Floor	28.50	1.66	303	258
Windows	-	2.91	-	-
Internal floors	28.50	1.63	298	256
Internal walls	11.0	1.57	92	84

Rationale for the variables for the modelling: undertaken approach for simulation studies

In this work, the effect of passive cooling strategies is simulated according to an adaptive thermal comfort approach, coherent with the likely European standard of BS EN 1521 (BSI, 2007) for retrofitting existing residential buildings, as described below.

Psychometric chart and thermal comfort analysis

As previously stated, Famagusta is located in the Eastern periphery of Northern Cyprus, which is known for its hot and humid summer. “CIBSE 2016 Weather files” adopted by Integrated Environmental Solutions (IES-VE) was used to produce the psychometric chart was climate analysis add-ins of the software automatically interprets the climate variables for a typical meteorological year (TMY) data for the location. So, the software that produces the psychometric chart can be used to plot the temperature and relative humidity that occurs over the period of 4382 hours CIBSE TM52 weather format climate data of the year. Different design specifications and comfort index parameters are represented by specific zones on the psychometric chart. The percentage of the hours that fall into different design strategy zones give a relative idea of the optimisation of indoor thermal comfort as shown in Figure 4.



(a) **(b)**

Figure 4. The psychometric chart for Famagusta and the amount of solar radiation of the prototype residential tower block.

Passive cooling design strategies into retrofitting: Shading, Night ventilation and Indoor set-point temperature

Firstly, the shading strategy is modelled to consider likely activation of the devices by occupants: therefore, the condition for it application in the simulation software is the amount of solar radiation arriving on the large glazed surfaces, which, in order to take into account the issue of overheating, is set to 100 W/(m^{2}K) (IES-VE, 2017). The shading devices, applied to every flat, are external venetian blinds. Within the simulation software, the shading type needs to be represented with a decrease factor of solar heat gains through the windows and with its position both internally and externally, which calibrates the related thermal performance.

Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment and lighting benchmark, night ventilation is modelled between 23:00 and 07:00 during the cooling season in particular only when the indoor operative temperature exceeds the cooling set-point, with an increase in the air-change rate of 0.5 h^{-1}, which is recommended as a value that is low but consistent with ventilation rates naturally achievable through single sided openings (CIBSE, 2016).

The comfort requirements from international standards such as EN 15251 (2007) are expressed in terms of operative temperature, the prototype case study RTB set-point regulation is performed according to this value. Therefore, T_{op} values of 26°C for cooling, according to what stated within EN 15251 (2007) for normal level of comfort expectations, are set for the energy need analysis of the prototype RTB. In this regard, since the CEN adaptive method provided in EN 15251 (2007) is valid for outdoor reference temperature up to 30°C, only its running mean temperature equation is considered for this study, which applies up to 33.5°C therefore it is more applicable for the Mediterranean climatic context. The parameters used in the building simulation are summarised in Table 3.

Table 3: Building simulation parameters.

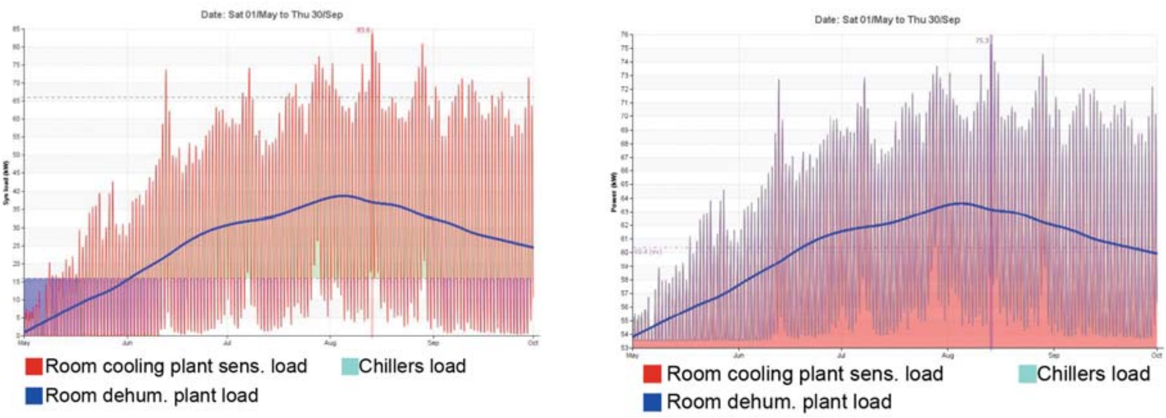
Parameter		**Values**	
Maximum ventilation rate during days (when Q_{op} *>23°C)		3 [h^{-1}] (from 6am to 23pm]	
Maximum ventilation rate during nights (when Q_{op} *>23°C)		2 [h^{-1}] (from 23pm to 6am]	
		200 [W/(m^2] (North, north-east, north-west direction) 300 [W/(m^2] (All other directions)	
Infiltration	0.1[h^{-1}]	**Cooling set-point (comfort levels)**	
Internal heat gains	4 [W/(m^2]	Ground floor	24°C
Short wave reflectivity of the façade	0.5 [-]	Typical floor	25°C
		Top floor	26°C

Results and Discussion: Performance of Base-case Model of Prototype Residential Tower Block (RTB)

The simulations section evaluates the thermal comfort conditions based on the standard CIBSE-TM 52: The limits of thermal comfort: avoiding overheating in European buildings (CIBSE, 2013). The results of the thermal performance of the base-case model were validated according to CIBSE AM11: Building energy and environmental modelling benchmarks including, the BS EN 13779: Ventilation for buildings and BS EN 13786: Dynamic thermal performance for buildings.

Cooling energy demand

In Figure 5, the cooling energy consumption is shown for the living zones (living room and bedroom 1) on the worst-case (level 10) sample flat. The initial observation is that the flat units greatly exceed the benchmark of 15kW/h. The flat on the typical floor is shown to have worse thermal performance than the one on the first floor. The worst performing flat is the top floor (three exposed external walls) corner flat. The living room in this unit is the worst performing zone with a performance that exceeds the benchmark by over eight times at a value of 83.6 kW/h. It is worth noting that the bedroom 1 exceeds the benchmark by over seven times with a value of 75.3 kW/h.



(a) (b)

Figure 5. The calibrated existing cooling energy consumption of the worst case top floor units' living room and bedroom 1 during the pre-retrofitting phase.

Evaluation of overheating assessment

This criterion was assessed by the total number of days in a calendar year where the exceeds 6°CHr while that zone was occupied (CIBSE, 2013). As previously stated in the literature, in compliance with criterion 2, a zone should exceed this value for no days (ibid). The results for the base case are shown in Table 4. As with criterion 1, the sample flat units are shown to exceed the benchmark with the corresponding top floor flat unit showing the greatest level of overheating. Within this flat unit the living room surpasses 6°CHr for 105 days and the bedroom 1 surpasses 6°CHr for 87 days out of 153 days respectively. This indicates that the zones within the flat struggle with a large percentage of time at very uncomfortable thermal conditions throughout the year. For TM 52 Criteria III, the highest values of ΔT are shown, with all simulated rooms in the ground, typical and top floor flats failed to pass the criteria. In all of these sample flats, bedroom 1 performs the highest peak ΔT with a value of 10°C due to its north facing orientation.

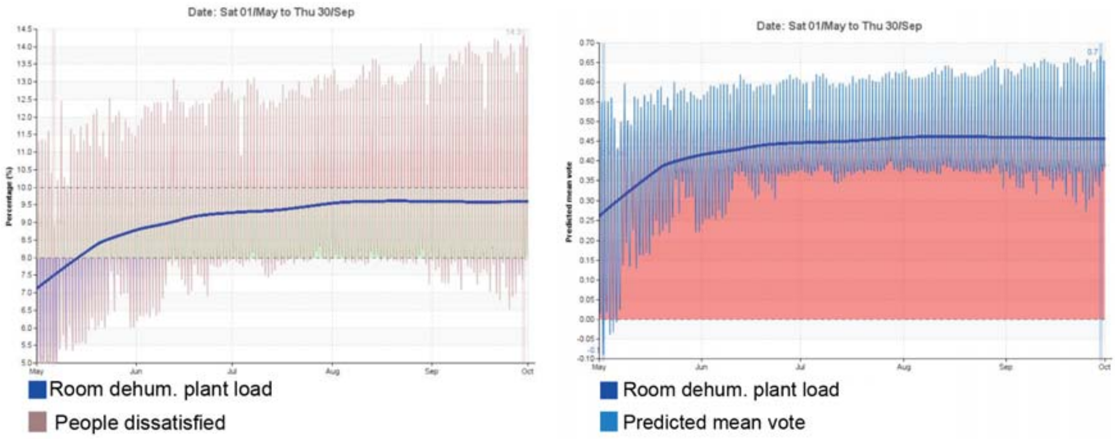
Table 4: Results for TM 52 Criteria II and III for study year (ΔT is room temp. minus maximum adaptive temperature)

Flat	Livingroom	Bedroom 1	Bedroom 2	Bedroom 3
		TM52 Criteria II Daily weighted exceedance (°Chr)		
Ground Floor	51	45	43	37
Typical Floor	60	48	62	69
Top Floor	60	47	61	69
		TM52 Criteria III Max. ΔT (°C)		
Ground Floor	5	5	4	4
Typical Floor	8	9	7	8
Top Floor	11	10	7	8

The flat on the typical floor is again found to perform better than the one on the top floor. The living room is observed to be the critical zone within the sample flats as it fails criterion 3. The differentiation in the performance of the flat on the first floor is attributed to the location of rooms. The unit with three exposed walls has reasonably reduced capacity for providing thermal comfort within the adaptive comfort limits. The living room in first floor flat unit and top floor exceed what 4°C by 4 hours and 9 hours annually, respectively.

Figure 7 illustrates that the zones under consideration within the case study RTB's sample flat units are found to exceed the acceptable limits of the CIBSE TM 52 criteria (both PPD and PMV). The least performing space is the living room as it incorporates the internal heat gains from the open plan kitchen design. The flat unit with poorer ventilation performance was shown to be flat 3 on the top and ground floor (flat 1). This is attributed to the opening ratios and material properties of the double-glazed windows. These flat units are constructed with three exposed external walls allowing for a higher rate of heat transfer.

Figure 6 summarises the overall cooling demand reductions are connected to the introduction of the variable set-point in summer are shown for all three representative sample flats. The results point out that during the cooling season, the cases reveal significant differences based on the adaptive set-point of the heavy weight construction materials, in particular for this base case model RTB, which is not provided with any insulation layer. Furthermore, it is important to highlight the fact that comparing base case and retrofitted case, the reduction in the cooling need assesses for the heavy weight constructions tend to decrease as the height of the floor level and orientation of the flat, while in case of implementation of passive strategies into retrofitting the trend is inverse.



(a) (b)

Figure 6. The overall results of the Predicted People Discomfort (PPD) and Predicted Mean Vote (PMV) of the base case prototype retrofit tower block.

It is important to highlight that, in terms of criterion 3, the bedrooms in each of the tested flat units also show exceedance of 4°C during the simulated summer period. This can be attributed to the classification of the bedrooms as a "night zone" which means it is only occupied at night. This means that the external night time temperature rises above a certain point whereby the addition of internal gains from occupants is significant enough to raise the temperature above T_{upp}. The results also indicate, in comparison, the living room is either partially or fully occupied at all times. This incorporates those periods where external daytime temperatures reach their maximum.

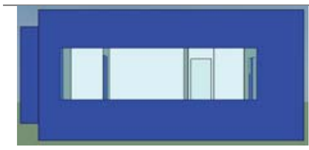
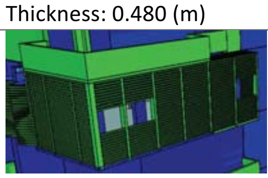
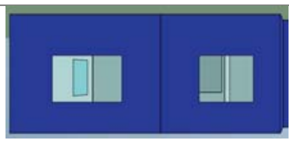
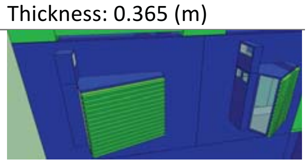
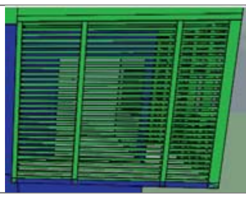
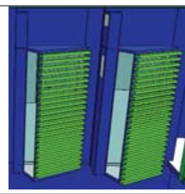
Passive cooling design strategies into retrofitting

The simulated and tested passive cooling design strategies are shown in Table 5 and 6. From the analysis, it can be seen that once again the passive shading strategies are the ones characterised by a stronger daily temperature variance, also due to the large glazed surface (which is not shaded in this case).

Table 5: Studied scenarios.

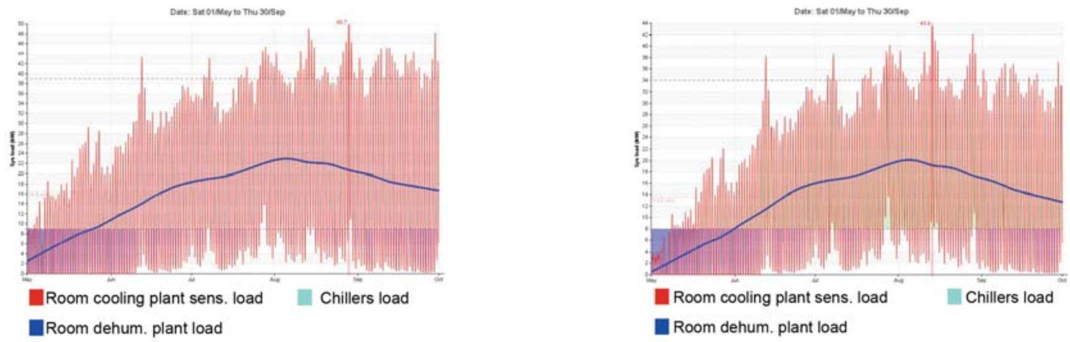
Scenario	Description
1	Base case with cross ventilation and shading
2	With external shading (50% Transparency) and without cross ventilation
3	Cross ventilation by providing opening between existing openings and implemented windcatchers

Table 6: Characteristics of the glazed surfaces for the different solutions.

Pre-retrofit	**Post-retrofit**	**Pre-retrofit**	**Post-retrofit**
Glazing type: Type A	U-value: 0.298 W/(m²K)	Glazing type: Type C	U-value: 0.299 W/(m²K)
Dimension: 460x120h/cm	Thickness: 0.480 (m)	Dimension: 140x120h/cm	Thickness: 0.365 (m)
			
Glazing type: Type B	U-value: 0.298 W/(m²K)	Glazing type: Type D	U-value: 0.312 W/(m²K)
Dimension: 190x230h/cm	Thickness: 0.400 (m)	Dimension: 110x230h/cm	Thickness: 0.125
			

*Corrected U-values determination according to the nominal U-values during the simulation.

According to the results of the dynamic thermal simulation, energy savings of around 46% are expected, with the main goal of the study to save 50%. As could be expected in a residential building located in a hot and humid climate zone of the study context, for the non-retrofitted case the cooling and heating (73%) comprise the biggest part of the total energy consumption (Ozarisoy and Elsharkawy, 2017). Figure 7 summarises the results of the proposed changes done in the model, the cooling consumption decreases 52% by implementing passive shading devices (exterior venetian blinds and internally operable ventilation openings); therefore a 30% reduction of cooling load for the prototype case building is also achievable by improving the building envelope (new U-value 0.15 W/ m^2K), by considering fitting external cladding with good thermal mass characteristics (Ozarisoy and Elsharkawy et al., 2017).



(a) **(b)**

Figure 7. The calibrated existing cooling energy consumption of the worst case top floor units' living room and bedroom 1 during the post-retrofitting phase.

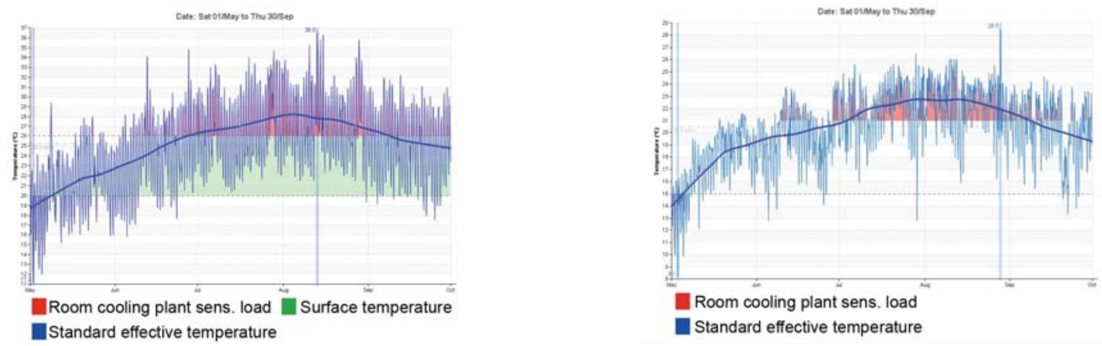
Specifically, in this case thermal bridges play an important role in energy consumption. One of the main objectives of the intervention is to be minimise their impact. As thermal bridges are not calculated correctly in dynamic simulations, in this case they have not been taken into account, knowing that, due to this factor, natural ventilation and air infiltration rate are major input parameters for calculating cooling demand. Results of the energy balance in more detail can be seen in Table 7. It is remarkable to note that the most important energy savings are due to changes developed in the natural ventilation through implementation of the internally operable ventilation opening systems on the building envelope.

Table 7: Energy consumption during the pre and post retrofitting.

	Pre-retrofit	**Post-retrofit**
Cooling (kWh/ m^2-year)	58.7	13.1
Lighting (kWh/ m^2-year)	29.3	25.4
Equipment (kWh/ m^2-year)	14.2	14.2
TOTAL (kWh/ m^2-year)	**102.2**	**52.7**

Findings

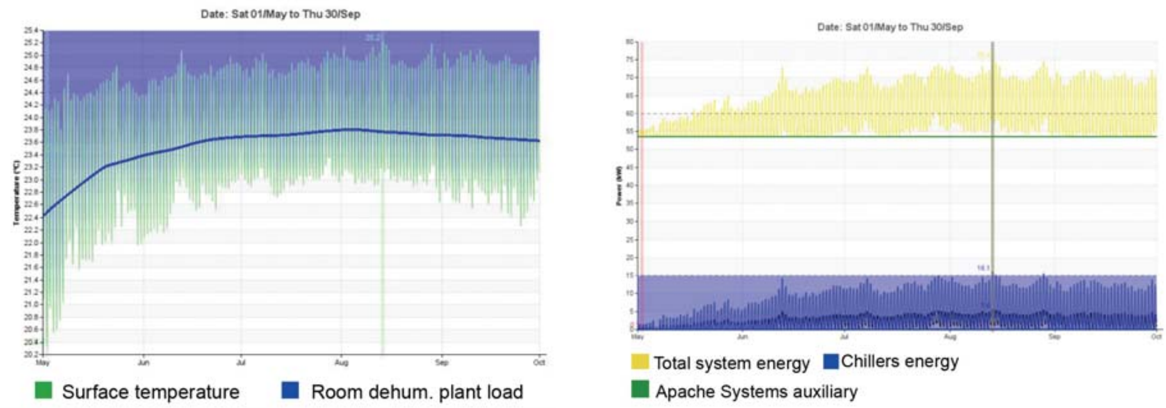
The cooling need trends are reported in Figure 8, one based on the conventional set-point and the other based on the adaptive comfort model; by comparing them, the different magnitude of cooling need assessment depending on the considered approach can be strongly appreciated, since the desired adaptive temperature in the worst-case scenario is significantly higher than 26°C. All three simulated and tested sample flats show the higher indoor air temperatures, during the occupied hours of the day because of the direct solar radiation through the unshaded large-glazed windows. The flat unit in the top floor at level 10, among the ground floor (level 1) and typical floor (level 7), has higher loads during the occupied hours, since it cannot release all the heat gained and stored during the day and during the night-time.



(a) (b)

Figure 8. Distribution of air temperature during the pre and post retrofitting phases in the worst –case scenario top floor flat.

Figure 8(b) shows the summer operative temperature trends in the retrofitted flat units and the cooling load related to the two set-point options, when external venetian blinds are used as a shading device. Figure 9 shows the summer operative temperature trends in the worst case top floor flat unit at level 10 when night ventilation is adopted as a free cooling strategy. The daily average temperature decreases and the daily variability increases due to the cooler conditions during the night-time, but the most important remark regards the fact that the behaviour of the wind catcher systems to become more similar to the passive design principles. This is due to the fact that night ventilation allows the internal mass to lose heat during the unoccupied hours by natural ventilation.



(a) (b)

Figure 9. Distribution of air temperature and cooling energy consumption of the worst case top floor flat by implementing wind catcher systems for cross ventilation strategy.

Additionally, starting from these base case studies, when the adaptive set-point is used, the decrease in the cooling need due to the additional ventilation is required, in particular for the heavier construction materials and its systems. This is due to the strong effect of heat loss from the heavy weight structures caused by additional discharge rate during the night-time. This is because, the adaptive indices have been developed according to the occupants' thermal sensations and preferences (Nicol, Humphreys and Roaf, 2012; Ferrari and Zanotto, 2012 and Nicol, 2017). In this study, the adaptive comfort temperature represents the climatization system set-point as autonomously managed by the occupants, according to the external climatic conditions. This is due to the fact that it takes into account a cooling need assessment quite respect the one referred to the implementation of passive cooling design strategies into retrofitting.

Conclusion

This paper aimed to evaluate the risk of overheating and potential ways to overcome this through the implementation of passive cooling design strategies (i.e. shading and natural ventilation) of a tower block in Famagusta, Northern Cyprus. When testing the base-case model, the top floor flat on level 10 has the worst thermal performance because of its proximity to the un-insulated roof, the effect of hot air movement into the space and the structural thermal behaviour characteristics of the RTB's envelope. It can be observed that there is a lack of diurnal temperature variation within the sample flat units which means the internal operative temperatures remain relatively high throughout the day and night, ranging from a maximum 36.5°C to a minimum of 28.5°C. This is not significant enough to induce night cooling. The external fabric; un-insulated roof and three exposed walls are a key determinant factor due to its high U-value, the surface area and the level of exposure to solar gains. This induces a high heat transmittance into and out of the top floor flats which has a significant effect on the operative temperatures of those flats.

Overheating is likely to occur at a frequent rate in the top floor flat's bedroom 2 and 3 than the living area. It can be seen that over 7% of the hours rose above the 28°C and the BS EN 1521 Category II upper limit when calibrated temperatures are evaluated in the living area using the CIBSE and the adaptive thermal comfort models. Respectively, high summertime temperatures (18% of the hours above the 26°C indicator) and warm discomfort (15% of the hours above the BS EN 1521 Category II upper limit) are also reported both in the bedroom 2 and 3. Finally, this study elucidates the potential applicability of passive cooling strategies to optimise thermal comfort at the worst-case top floor flat in peak summer. The findings show that the cooling consumption decreases by 52% by implementing passive design strategies (exterior venetian blinds and wind catcher systems). From this study, it appears the passive design principles would be energy-efficient and cost-effective for retrofitting RTB. This is a crucial finding that needs to be investigated in further research to assess and optimise risk of overheating and understand occupants' thermal comfort when enhancing "night cooling" effects in RTBs in this Mediterranean climate.

References

British Standards Institution [BSI]. (2007). BS EN 15251: 2007: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics; BSI: London, UK, 2007.

CIBSE (2016). Environmental Design, CIBSE Guide A. London, UK: Chartered Institution of Building Services.

Ferrari, S. & Zanotto, V. (2009). EPBD and ventilation requirements: uneven inputs and results in European countries, in Proceedings of the 30th AIVC Conference – Trends in High Performance Building and the Role of Ventilation, Berlin, 1-2 OCT 2009.

Integrated Environmental Solutions (IES). (2017). IES Software Validation. Available at: http://www.iesve.com/software/software-validation (Accessed 14 September 2017).

Kottek, M., Greieser, J., Beck, C., Rudolf, B. & Rubel, F. (2006). World Map of the Köppen Geiger climate classification updated.Meteorology.Z.,15,259N263.DOI: 10.1127/0941N2948/2006/0130.

Nicol, F., Humphreys, M. & Roaf, S. (2012). *Adaptive Thermal Comfort: Principles and Practice*, Routledge, Taylor *and Francis Group.*

Nicol, F. (2017). Temperature and adaptive comfort in heated, cooled and free-running dwellings. *Building* Research & Information, pp.1–15.

Ozarisoy, B. & Elsharkawy, H. (2017). Retrofit Strategies for the Existing Residential Tower Blocks in Northern Cyprus. Passive and Low Energy Architecture (PLEA) Conference, Edinburgh, Scotland.

Santamouris, M.; Pavlou, K.; Synnefa, A.; Niachou, K.; Kolokotsa, D. (2007). Recent progress on passive cooling techniques Advanced technological developments to improve survivability levels in low-income households. *Energy Build. 39*, 859–866.

State Planning Organisation—TRNC (Devlet Planlama Orgutu—KKTC). Economic and Social Indicators Statistics. (2015). Available online: http://www.devplan.org/Frame-eng.html (accessed on 8 August 2017).

Zahiri, S. & Elsharkawy, H. (2017). Building Performance Evaluation for the Retrofit of Council Housing in the UK: A case study of a tower block in London, Passive and Low Energy Architecture (PLEA) Conference, Edinburgh, Scotland.