NATURAL VENTILATION AS AN ARCHITECTURAL INSTRUMENT: CASE STUDY OF GAZIANTEP, TURKEY

Abstract

One of the most common complaints expressed by residents of social housing in southeastern Turkey is their thermal dissatisfaction. Sprawling rapidly throughout different regions around the country, the typology of the Turkish Mass Housing Administration (TOKI) causes a permanent complaint related to outdoor and indoor thermal conditions by users. As a consequence of this homogenization effect, overheated and underheated conditions are experienced in these 'naturally ventilated buildings' designed with few considerations regarding the surrounding environments. Therefore, in this paper, we analyze how renewable sources could be used to alleviate thermal related concerns expressed by residents of one of these projects. Through an investigation on natural ventilation, predominant airflow is studied in warm periods (May to October) as an alternative to reduce the reliance on fossil fuels that are used for cooling purposes. This paper investigates natural ventilation as a passive strategy that has been used in vernacular architecture of hot and dry climate regions in Turkey and can be articulated as an architectural instrument to conceptualize new alternatives to the current TOKI housing model.

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Keywords

TOKI, natural ventilation, mass housing, external simulation, IES VE

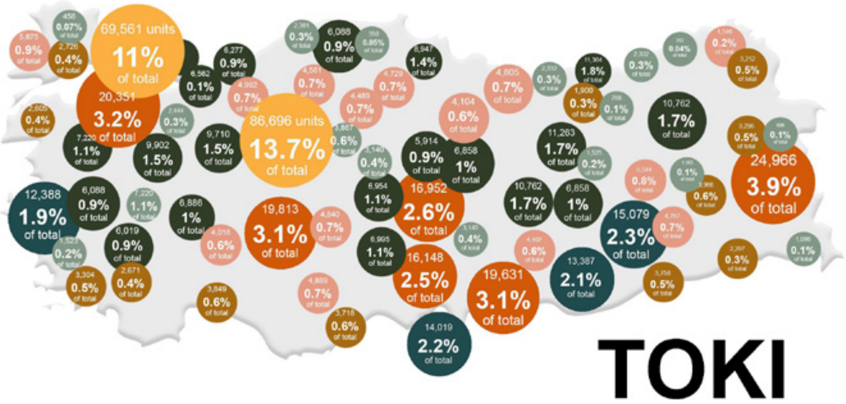

Figure 1: TOKI production in Turkish cities. Population: 82,735,929. Urban population: 62,061,946. TOKI total unit: 630,579.

Introduction

During the industrialization period, the migration from rural regions to urban areas caused high population rates in cities and the construction of informal housing in many countries (Keles, 2006; Majale, 2008). Informal settlements are described as over-crowded, temporary, probably illegal, and unhygienic (Uzun et al., 2010). There have been worldwide initiatives to deal with this rapid urban growth and informal settlements (Takeuchi et al., 2008). Through these policy-supported actions: (i) governments can build housing units to rent (full or subsidized) or give them to the citizens; (ii) governments can make prices of housing more affordable for people; or (iii) governments can take steps to promote homeownership by providing loans for citizens (Choguill, 2007). In the case of Turkey, the current housing deficit is solved through a governmental institution called TOKI, which is the Turkish acronym for the Mass Housing Administration (Figure 1).

In the last 35 years, this entity has replicated the model of large-scale, high-rise typologies all over the country and its projects have become the object of multidisciplinary research. Commonly, TOKI housing has been studied in social and political sciences. However, there has not been much investigation about their environmental sustainability. For example, housing quality and the performance in TOKI developments has been unnoticed. Applied research conducted on energy efficiency in these buildings is relatively limited.

Looking into the big picture in 2006, residential electricity consumption was 35% of the total energy consumption in Turkey (Dilaver, 2009). In 2009, it was estimated that nearly 90% of buildings didn't have sufficient heat insulation, which caused over-cooled apartment units in cold periods (Association for Energy Efficiency, 2009; energypedia, n.d.). Within this frame, this research examines a TOKI residential setting in order to produce baseline data and help to provide guidelines for future developments carried by the TOKI agency.

Gur and Dostoglu (2011) indicate that 70% of TOKI users move into these projects due to the low cost compared to other housing possibilities. Nationwide, the TOKI administration is forced to meet low-income people's necessities within financial margins that result in pitfalls to meet users' expectations related to sustainability.

In this panorama, TOKI separates from being a sustainable housing solution that, besides being economically viable, is also technically feasible, environmentally friendly, and socially satisfactory that Tolba (1987) mentions is needed for a sustainable development. Following these criteria, TOKI housing can be self-reliant and cost-effective without decreasing environmental quality. However, in reality, TOKI projects have received many critics. In this research, we focus on one: their thermal performance; residents complain frequently about indoor climate conditions. In the winter, residents express problems in heating their units while in hot periods they deal with overheated units.

Previous research on TOKI shows that design decisions on urban form, residential typology, and building enclosure generate negative outcomes (Savran, 2014; Turan, 2010; Karaca, 2008). Therefore, conclusions are conveyed to address environmental strategies such as solar control, daylighting, and natural ventilation to alleviate problems using natural resources. Particularly, using clean energy to decrease peak values of indoor temperatures.

Methodology

CASE STUDY

This research is conducted on a TOKI case study built in the city of Gaziantep. This city has a population of 2 million people and is located in the South-Eastern Anatolia region of Turkey. In this location, buildings demand high cooling loads because of the hot and dry climate. Therefore, there is potential of using prevailing winds to alleviate hot temperatures, cooling the indoors and bringing fresh air.

As a climate zone 3B (ASHRAE 90.1) and Csa-Mediterranean Climate (Köppen), winters are cold while summers are usually hot and dry with temperatures above 30°C (Turkish State Meteorological Service). In this sense, a weather data analysis shows that in at least 2,600 hours per year (30%), there is no high humidity that can cause thermal stress, besides other conditions (annual average temperature: 16.4°C, mean relative humidity: 56.3%, mean moisture content: 0.006 kg/kg which is in nominal comfort range). While the relative humidity in the region is low, evaporation is high in summers (Figure 2). It favors the potential of using the city's southwest prevailing winds for natural ventilation of buildings.

Typical flow regimes and their interaction with a building form and its envelope are observed through computational fluid dynamics (CFD). This methodology allows comparing design iterations to optimize natural ventilation. The analysis on a baseline model allows to formulate a proposal developed around the effects of porous (voids and openings on the building mass) in the built form. For multi-story buildings, the effect of voids has proven to be an essential aspect to decrease cooling loads (Muhsin et. al, 2017).

In general, TOKI projects may present difficulties in terms of building orientation that might limit natural ventilation. The TOKI project in Gaziantep, which is called Etiler, was studied as a case study. It was built in 2012 (Figure 3). The Etiler Project is composed of six rectangular 12-story towers arranged on an irregular plot with inadequate possibilities to benefit from prevailing winds. This is observed through contour-velocity diagrams generated in IES-VE that were employed as an input hourly data (TMY15 weather file) for Gaziantep.

In a resident survey previously carried in the TOKI Etiler project, it is observed that an active operation of windows during the day brings air indoors (Bay, 2019). Therefore, besides external airflow simulations, internal CFD simulations are carried to observe the effects of window-to-wall ratio and windows operation indoors on summer days.

CFD SIMULATIONS

Both external and internal simulations were tested in IES-Microflo. The time lapse of external simulations was a 5-month period (warmer months from May to September), while the time lapse of internal simulations was applied to single instances in time (May 17, June 14, and September 21). Through indoor simulations and energy analysis, indoor temperature, air changes per hour in a unit, and percentage of people dissatisfied were obtained and compared in baseline and proposed models.

Analysis of the aerodynamic flow effects start with the TOKI baseline model as the first step. It is obtained that this typology with central core does not create significant pressure differentials when the model is exposed to the predominant airflow.

These external simulations show the flow around the towers. These are the result of computing wind direction, meteorological wind velocity, and exposure type to obtain streamlines in a CFD grid. Through a graphical analysis of velocity profiles, it is possible to observe the difference of airflow rate on windward and leeward facades in different levels. Results indicate that wind speeds are not adequate for single or cross ventilation particularly in low and top levels (Figure 4).

On a second step, a new typology is tested: a mid-rise (5-story) courtyard building (Figure 5). It examines the flow behavior in courtyards by gradually changing their "width-to-height ratio" and their openings. These models have the same orientation as the TOKI project and show that courtyards with a 2.5 "width-to-height ratio" have faster velocities under funnel and diverting effects.

On a third step, the courtyard building model is aligned to the prevailing wind direction. It results in more homogeneous velocities along courtyards with "width-to-height ratio" of 1.25. Additionally, models show that in narrower courtyards (w/h of 3.75) a larger funnel effect is proportional to a more constant acceleration of the prevailing streams (Figure 6).

These following steps help to reformulate the new typology. The concept of 'porosity' is studied with basic courtyard models to understand the benefits of void spaces through courtyards, terraces, porches and balconies as transitional spaces. These provide similar velocities across each one of the floors and units around a courtyard by enhancing the interconnection of air flow with their perimeter.

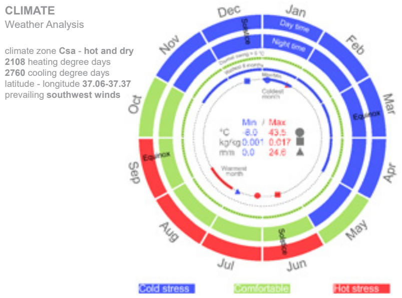

Figure 2: Weather analysis in Gaziantep (IES-VE).

Figure 3: TOKI Etiler Project in Gaziantep, 2019.

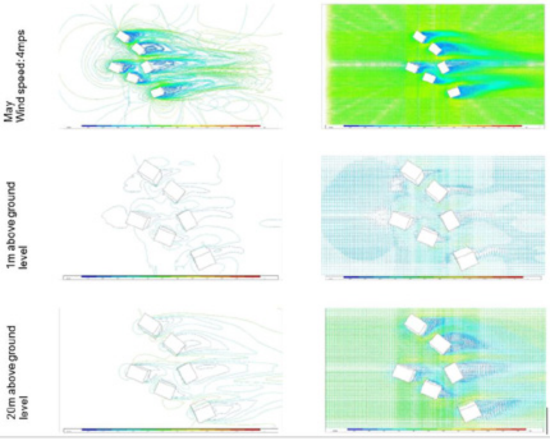

Figure 4, Step 1: Outdoor CFD analysis during May.

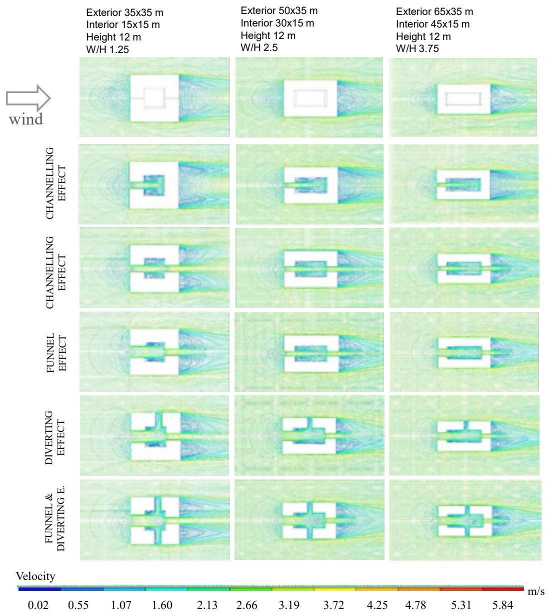

Figure 5, Step 2: Courtyards of w/h proportions of 1.25, 2.5, and 3.75 under different aerodynamic changes parallel to prevailing wind (Bay, 2018).

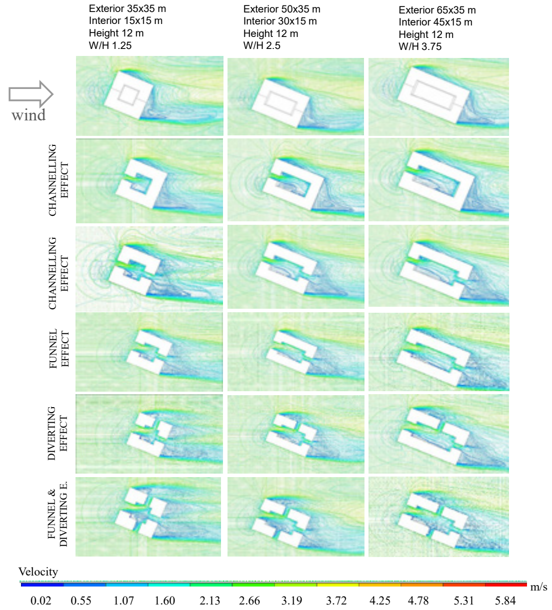

Figure 6, Step 3: Courtyards parallel to prevailing wind (Bay, 2018).

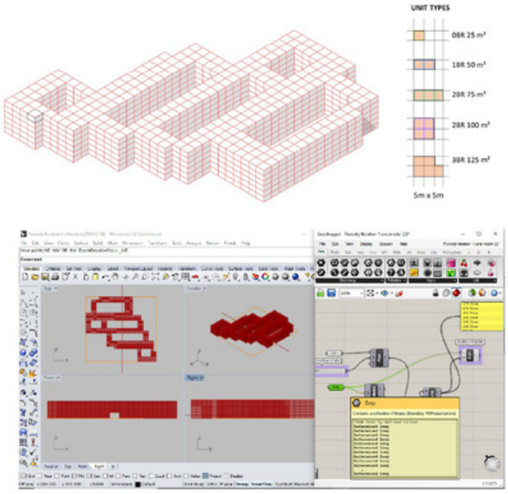

Figure 7: Model generation-proposed case study.

GENERATIVE DESIGN

By using the idea of a 'porous structure,' the air flow potential through building massing is explored through 'generative design techniques.' A 'code' is applied on a set of 'cells' that represent apartment units from the scheme selected in the previous step. Under the influence of 'prevailing winds,' units are subtracted to create a 'porous' volume that enhances cross ventilation and cools down internal weather. The Grasshopper plug-in for Rhinoceros allows processing the following algorithmic and geometrical operations (Figure 7).

At the building scale, positioning void spaces as vents is carried through data validation. In a random selection, 'cells' are omitted from the massing by the development of a culling list. Three components that take Boolean values (true/false) generate a list of 'selected' cells that are subtracted from the whole. A ratio of porous (0%–60%) can be controlled through 'slider components' that determine the percentage of reduction. With this methodology, connections between courtyards augment 'diverting effects' at ground level. In a subsequent step, prevailing winds are formulated as a 'generative vector' that, based on its magnitude, direction and sense, perforate the 'building volume.' Then, cells intersected by this vector are omitted from the group by determining their distance from it.

The intensity of air flow can be characterized by a 'user-defined number.' As an attractor, this vector makes the building form evolve through 'slider' components that define an 'area of influence.' Cell units inside this field of action are omitted. Overall, these processes are oriented to displace, reorient, and re-scale iterations that can be analyzed through CFD iterations to reach a fitness proposal.

After outdoor CFD in IES-VE and density analysis in Grasshopper, a building structure with 40% of porous structure was selected (Figure 8). In more porous models, there is more airflow moving through the courtyards and moving into the apartments (increment of air exchanges in the units). Under this choice, it is observed that speed levels and outdoor temperatures in ground and first levels get closer to the values obtained from level 2 to level 4. Without less mass on top levels, openings seem to influence a full flushing courtyard area, this is dependent on having width-to-height ratios larger than 2.4.

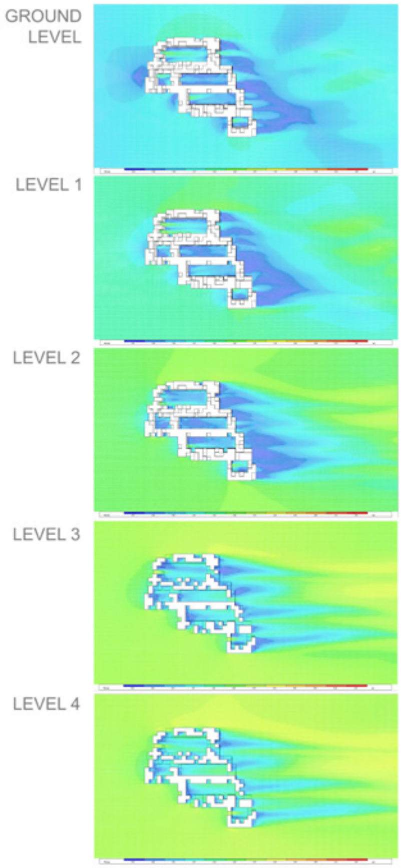

Figure 8: Final model–60% mass, 40% porous.

Results

While inputs in external simulations are wind direction, wind speed, and domain size, in internal simulations, boundary conditions and loads are the main inputs. Additionally, surface temperatures of external walls are manually added for model accuracy (counting radiation from solar gains).

The proposed model (5-story courtyard building) explores aerodynamic effects in relation to street canyons and courtyards. Different width-height aspect ratios were tested to observe the adequate velocity and temperature of the external surface when channeling, funnel, or diverting effects were generated through the form of the proposed residential volume. As a manner to move forward in the idea of 'porosity,' parametric tools were employed. With this, more advanced '3D' porous geometries were generated controlling the size, form, number, and location of 'porous' in a building geometry.

Air flow and heat transfer processes occurring within and around buildings were observed through CFD analysis. Specified boundary conditions, including effects of local climate and internal energy sources such as people, were used for detailed internal simulations. The air velocity through the building was observed in periods of high and low temperatures.

Comparisons between current TOKI housing and the proposed courtyard building model are studied in three key performance indicators: indoor temperatures (T), predicted percentage of dissatisfied (PPD), and air changes per hour (ACH). The proposed building shapes predominant westerly winds (+2.5 m/s) through mainly funnel and diverting effects when compared with the baseline case. Indoor summer peak temperatures are lowered through building form (1.5–2°C), also operative temperatures are lowered corresponding to higher percentages of satisfaction. In terms of ventilation rates, 33% of improvement on ACH was obtained compared to the TOKI Etiler Project. On June 14, overall air change in proposed units doubled (Table 1).

Date	**T(°C)**		**ACH**		**PPD (%)**	
	B (Level 3)	P (Level 3)	B (Level 3)	P (Level 3)	B (Level 3)	P (Level 3)
May 17	22.8	20.8	1.8	2.46	6.7	6.3
Jun 14	22.3	21.2	4.6	9.6	10.5	9.3
Sep 21	23.1	21.7	2	3.96	9.3	7.7

Table 1: Comparison between baseline and proposed cases: Temperature, air changes, and people dissatisfaction.

Conclusions

Under the discussed case study, high-rise is a solution to deal with density and demand. TOKI projects provide a safer and healthier infrastructure and ownership to low-income communities, although resident's well-being might be undermined by functional constraints. This cost-effective solution is limited and not sustainable. This choice brings new 'typological' alternatives analyzed through energy simulations and computer fluid dynamics (CFD).

The conclusion of this paper is that proposed typology is better by achieving these improvements and reaching thermal comfort because of cross ventilation which we can quantify. The proposed project also has the possibility to bring housing closer to human needs and to the environment. This will help to alleviate thermal-related problems in consonance with 'building forms' derived from 'vernacular architecture' in this region.

Ventilation strategies in a particular design can be evaluated based on the location and climate. This research shows an improvement to the problematic presented in a governmental housing program. Proposed ideas showed an improvement of occupancy comfort, energy/cost savings by using renewables, and reducing the energy use intensity in residential buildings.

Like examples seen in the vernacular architecture of the region, courtyard is one of the important examples of porous structures that allow regulating harsh conditions of the climate through passive cooling. Proposed alternative urban patterns will favor air flow and heat transfer processes.

References

Association for Energy Efficiency. (2009). Retrieved March 2018, from http://www.enver.org.tr/modules/mastop_publish/?tac=17

Bay, E. (2019). Life in a High-rise: Surveying Opinions and Expectations on Social Housing in Turkey. *ARCC 2019 International Conference,* 401–410.

Bay, E. (2018). Enhancing Natural Ventilation through Massing: New Possibilities for Turkish Mass Housing. *Prometheus, 3,* 120–127.

Choguill, C. L. (2007). The Search for Policies to Support Sustainable Housing. *Habitat International, 31,* 143–149.

Dilaver, Z. (2009). *Residential Electricity Demand for Turkey: A Structural Time Series Analysis.* https://aaee.at/2009-IAEE/uploads/fullpaper_iaee09/P_140_Dilaver_Zafer%20_29-Jun-2009,%20 16:51.pdf

Energypedia. (n.d.). *Turkey: Energy Efficiency in Buildings.* Retrieved May 2019, from https://energypedia.info/wiki/Turkey-_Energy_Efficiency_in_Buildings#cite_note-Assosiation_for_Energy_Efficiency:_http:.2F.2Fwww.enver.org.tr.2Fmodules.2Fmastop_publish.2F.3Ftac.3D17-1

Gur, M., & Dostoglu, N. (2011). Affordable Housing in Turkey: User Satisfaction in Toki Houses. *Open House International,* 49–61.

Karaca, M. (2008). *Energy Efficiency of Housing Development: A Survey over Housing Development Projects of Housing Development Administration of Turkey* [M.Sc Thesis, 92–143]. Gazi University.

Keles, R. (2006) Kentlesme Politikasi. *Imge Kitabevi,* Ankara.

Majale, M. (2008). Employment creation through participatory urban planning and slum upgrading: the case of Kitale, Kenya. *Habitat International, 32,* 270–282.

Muhsin, F., Tusoff, W. F. M., Mohammed, M. F., & Sapian, A. R. (2017). CFD modeling of natural ventilation in a void connected to the living units of multi-story housing for thermal comfort. *Energy and Buildings,* 1–16.

Savran, S. (2014) *Evaluation of TOKI Low Income Housing Areas within the Perspective of "Adequate Housing": The Case of Ankara Kusunlar* [M.Sc Thesis, 123–129]. Gazi University.

Takeuchi, A., Cropper, M., & Bento, A. (2008). Measuring the welfare effects of slum improvement programs: the case of Mumbai. *Journal of Urban Economics, 64*(2008), 65–84.

Tolba, M. K. (1987) *Sustainable Development: Constraints and Opportunities.* London: Butterworth, 86–87.

Toplu Konut Idaresi Baskanligi https://www.toki.gov.tr/

Turan, I. (2010). *The Evaluation of the Social Housing Schemes of the Mass Housing Authority of the Prime Ministry of Turkish Republic in the Framework of Sustainable Architecture: Bezirganbahce Example* [M.Sc. Thesis, 154–156]. Istanbul Technical University.

Turkish State Meteorological Service. https://www.mgm.gov.tr/files/en-us/climateofturkey.pdf

Uzun, B., Cete, M., & Palancioglu, H.P. (2010). Legalizing and Upgrading Illegal Settlements in Turkey. *Habitat International,* 204–209.