Passive Heating and Cooling Potential Strategies: A Comparison between Moderate Summers and Warm Winters Climate Zones

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Abstract: In this work, a comparison between different potential natural ventilation strategies used in different climate zones are investigated. As an example of moderate summer climate zone, London city has been selected, while Dubai city has been selected as a warm winter climate zone. The influence of external wind speed and pressure was studied using Autodesk Flow Design Software. Then CFD simulations have been generated inside the building using IES Virtual Environment software to study the indoor ventilation (Micro-Flow analysis) and to demonstrate the success of the adopted potential strategies in enhancing the indoor climate conditions. Hourly Analysis Program (HAP) was used to calculate the cooling/heating load of the building and to check the energy savings. The results demonstrated that comfort conditions within the interior space of the building were met during certain months of the year using passive heating/cooling strategies alone (without the need of HVAC system). HAP energy modeling results showed that the annual space cooling for Dubai model dropped from almost 58,000 kW per year to almost 42,000 kW with a total energy savings of 18.6% (including all energy consumption parameters). On the other hand, London model results showed that the annual interior space heating dropped from almost 36,000 kW to almost 28,000 kW with a total energy savings of 16.4%.

1. Introduction

Buildings can consume plenty of energy, especially at harsh climates such as extreme hot and cold temperatures. HVAC systems are responsible for most of this consumed energy [1]. Heating is simply increasing the indoor temperatures of the building at cold climates while cooling is lowering the indoor temperatures at hot climates. Ventilation is the introduction of outside fresh air into the inside of the building, moving this fresh air around the building to make use of it in cooling or heating as well as reducing any pollutants produced from inside the building. This fresh air can improve the quality of air inside the building to maintain a healthy environment [2]. Although the concept of natural ventilation is very old, it has been generally overlooked in the design of buildings in the past few decades, the circulation of air inside buildings has been mostly done using heavy and complicated equipment within the HVAC system. Recent developments of green building standards and codes highlighted the importance of natural ventilation as one of the low energy systems worth considering [3]. Natural ventilation can be done in several methods depending on many factors such as building location, building envelope, height, surrounding buildings, building use and climate [2]. Stack ventilation is commonly used for multi-story buildings, cathedral ceiling buildings and many houses with near-top
windows [4], while cross ventilation “wind effect ventilation” can be done by locating openings or windows on opposite sides of the building [5]. This creates air breeze driven by the wind speed forcing air to enter the structure from one side and exit from the other [6]. Some buildings successfully employed more than one natural ventilation strategy (mixed strategies) such as the Queens Building of De Montfort University in Leicester, England [7] which combined global/local and stack/wind ventilation techniques. Another notable building where natural ventilation strategies were successfully utilized is Apple Park [9], the headquarters of Apple Company in California, the building is the largest globally to be naturally ventilated and it can reduce the need for the HVAC system to function during nine months of the year. Moreover, the effect of natural ventilation on energy can be tremendous, it was reported by the British Research Establishment Conservation Support Unit (BRESCU) that in comparison between naturally ventilated office building and air-conditioned offices, naturally ventilated buildings can lower the energy used for cooling the buildings in the range of 14 kWh/m² to 41 kWh/m² every year [10].

In this work, natural ventilation is studied based on building orientation, courtyard effects, cross ventilation and stack ventilation.

2. Research methodology and strategies
The study aims to assess the value of natural ventilation strategy applied to the same building located at two different locations. The first location is Dubai-UAE, and the second location is London-UK. The climate of both cities is relatively contrasting. Hot and humid in Dubai at summer that requires cooling and dehumidification. On the other hand, the weather in London is relatively cold and requires heating systems. The result of both models shall be compared together in terms of better ventilation results, desired temperatures achievement and better energy consumption reduction percentages. To achieve these objectives, this study will follow to the below procedure:

- Selecting a proposed location for the building: studying the area, dimensions, site characteristics, site potential and limitations, and existing buildings neighborhood facilities
- Rotating the building to the optimal orientation and comparing the results in terms of outdoor ventilation using Autodesk Flow Design Software.
- Suggesting a natural ventilation scenario and comparing the results of Dubai and London as described above
- Generating CFD Microflow analysis by using IES Virtual Environment software (IESVE) to detail the wind circulation inside the building and demonstrate the adopted strategy towards enhancing the indoor climate conditions, then comparing the results of the natural ventilation effect on internal zones.
- Cooling load calculations and energy modeling [11] shall be investigated using Carrier Hourly Analysis Program (HAP) to check the energy savings due to the adopted natural ventilation strategies.

3. Background
3.1. Climate Conditions:
Dubai climate is extremely hot in summer and relatively warm in winter. Temperatures are relatively diurnal (high daytime records and minimum after night-time). The hottest and most humid times are in July and August (44 °C & 60% RH). However, moderate climate conditions start from mid-November to the end of April approximately. So heating is not required in designing the HVAC system. However; cooling may be required all along the year. The direction of the prevailing wind in Dubai is North-West with average wind speeds varying from 11 km/hr to 23 km/hr. A slight increase in average speeds is expected from February to March. On the other hand, London climate is influenced by the effect of warm drifts from the North Atlantic Ocean, making it warmer and mistier than many places in Europe. London modest high temperatures at summer days with low winter temperatures that are above freezing, rainfall is regularly occurring all around the year. Roughly winters may have snow falling but rarely
adds to few millimeters deep. However, the coolest month is January, the warmest is August and the wettest is December. The prevailing wind direction is south west.

3.2. Case-Study Building

The considered building area is almost 500 m². It consists of multiple rooms with mixed usage such as offices, library and a gym with wet and service areas. A courtyard is enclosed within a building. A lounge represents the largest open area inside the building with an approximate area of 150m² as seen in Figure 1. The ceiling of the building is sloped and symmetrical from both sides. The same building is used in both climate zones in order to compare and evaluate the success of the proposed strategies. The L-shaped building design is expected to enhance the outdoor natural ventilation than a square building design as if a courtyard is enclosed within the building L-shape, it will be bounded by the two wings of the building.

![Figure 1: Case-Study Building Plan](image)

3.3. Natural Ventilation (passive heating/cooling) strategies:

The strategies used to enhance the natural ventilation inside the building can be summarized as follows:

- Rotating the building into prevailing wind direction[12].
- Increasing the windows of the building at lower level to enhance cross ventilation inside the building

- Introducing a pitch on the ceiling with 1-meter height difference between the two sloped roofs to accommodate for new windows openings at the high-level of the building new ceiling. The pitch is rotated into the prevailing wind direction in Dubai model, and against wind direction, in London model, as seen in figures 2 and 3 respectively.

- Introducing an isolated courtyard within the external building enclosure to enhance the natural ventilation. The effect of courtyard ventilation is simply similar to an air-well that serves as a fresh air intake source for the building enhancing the indoor ventilation.
4. Results and Discussion

4.1. Outdoor Ventilation:

To enhance the wind circulation around the building, it was rotated towards the prevailing wind direction. Moreover, a courtyard has been enclosed within the building external area. The proposed scenarios were analyzed and studied using Autodesk Flow Design software. Figures “4 and 5” show the results for Dubai model while Figures “6 and 7” show the results for London Model.

For Dubai model, the baseline scenario “Figure 4” predicts high wind speeds before the building, however it fails to predict a good circulation or wind after the building, this is why a courtyard can be used to enhance the pressure gradients before and after the building as well as the air circulation after the building (in the courtyard itself). Lower pressure values and enhanced wind circulation in the courtyard will have a great effect on the natural ventilation for the building. However, the second scenario “Figure 5” “which includes rotating the building into prevailing wind direction and adding an external courtyard” holds good for both wind speed, the vacuum pressure in the courtyard, pressure gradients before and after the building, as well as good circulation in the courtyard. This scenario can be imagined as having a good natural fan in series with the building. The simulation presents that the second scenario is the optimal strategy with a clear impact on the external wind velocity and wind pressure on the external envelope of the building. Moreover, the courtyard design strategy creates a Micro-Climatic area with a potential for better-ventilated space.

Based on the same criteria for Dubai model, rotating the building into the prevailing wind direction and adding an external courtyard enhanced the CFD results of wind speed and pressure gradients in London model. It can be clearly noted that CFD results for base models show that there is only one side of the building where the wind effects take place (the side of the prevailing wind) while the wind effects are almost negligible on the other sides, even if a courtyard is enclosed within the external building envelope. This highlights the importance of proper orientation in urban construction as a successful strategy in enhancing the natural ventilation effect. Hence, a better natural wind circulation was clearly visible on both wings of the building with the highest pressure on the main elevation. Moreover, the courtyard as a natural ventilation strategy based on better wind circulation can be clearly seen in figures “5 and 7”. A closer look at these figures shows how the courtyard serves as an air well for the building that creates a fresh air intake source for the internal building spaces enhancing the potential of indoor ventilation.
Figure 4: CFD results - Base model - Dubai

Figure 5: CFD results - Prevailed wind rotation and courtyard - Dubai

Figure 6: CFD results - Base model - London
4.2. Indoor ventilation
The study proceeds further to examine the internal Micro-Flow indoor ventilation using Integrated Environment Solutions software (IES). A common practice is to use the largest open space enclosed within the building to detail the wind circulation inside the building. The software is capable of simulating complex building geometries with different climate zones and locations. The results of the software include wind circulation contours, wind speeds, and temperatures as well as building energy requirements. These results can be enough to review the success of the adopted strategies in enhancing indoor ventilation. IES results are shown for the largest building area (lounge, 150 m²) in Figures “8 and 9” for Dubai and London respectively.

The simulation of Dubai model was done in the month of January (winter) while the simulation of London model was selected to be done at August (summer). The results show that internal air circulation is achieved with different air temperatures for both Dubai and London model. At Dubai winters, the majority of the internal temperatures figures are around 20-25 °C. On the other hand, at London summers, the majority of internal temperatures are figured around 24-25.5 °C. For both models (Dubai and London), wind circulation and air velocity were achieved where the internal airspeed is allocated between 0.03-0.07 m/s. The simulation results for Dubai model demonstrate that the comfort zone at the internal building space can be achieved in winter seasons based on passive cooling strategies alone, this means that there is no need to switch on the air conditioning during the months of winter (November-February). Similarly, the results also showed that the comfort zone can be achieved at London summer based on passive heating methods alone and there is no need to switch on the heating system at summer months (April-August).

4.3. Building Cooling load and energy modeling
The study continues to detail the energy savings by simulating the building energy requirements for the baseline model of the building (without passive cooling/heating) then study the effect of switching off the HVAC system during winter (Dubai) and summer (London) on the cooling/heating load and energy consumed within the building (Natural ventilation model). Carrier HAP software was used to model the system due to the adaptability of the software to the proposed model as well as the flexibility of the software in modeling district cooling/heating systems.

In general, the main electrical consumption contributors to the building electrical load is cooling/heating load, HVAC equipment load (pumps, fans), lighting load and building receptacle load (plug load). The case study building heating/cooling system is proposed to be from an external source (district cooling/heating) where an external supplier is responsible for the delivery of chilled water (for cooling) or hot water (for heating) of the building. However; the HVAC equipment (pumps, fans, fan-coil units) are still integrated within the building HVAC system.
HAP energy modeling results showed that the annual space cooling (Dubai) dropped from almost 58,000 kW per year to almost 42,000 kW with a total energy savings of 18.6% (including all energy consumption parameters). On the other hand, London model results showed that the annual interior space heating dropped from almost 36,000 kW to almost 28,000 kW with a total energy savings of 16.4%. Results of HAP energy consumption parameters are listed in table 1 below.

Table 1: Comparison between building energy requirements and total energy savings-Dubai and London

| Parameter/Unit        | Dubai Model | Natural Ventilation Model | Percent Savings | London Model | Natural Ventilation Model | Percent Savings |
|-----------------------|-------------|----------------------------|-----------------|--------------|----------------------------|-----------------|
| End Use               |             | Baseline Model             |                 | Baseline Model |                             |                 |
| Interior Lighting     | Electric    | kWh                        | 23,314          | 23,314       | 0 %                        | 23,314          | 0 %             |
| Space Cooling         | Remote CW/HW| kWh                        | 58,023          | 42,852       | 21 %                       | 35,625          | 20.5%           |
| Pumps                 | Electric    | kWh                        | 10,950          | 8,786.7      | 20 %                       | 5,065           | 18.3%           |
| Fans - Interior       | Electric    | kWh                        | 25,222          | 20,453       | 19 %                       | 25,725          | 19 %            |
| Receptacle Equipment  | Electric    | kWh                        | 12,856          | 12,856       | 0 %                        | 12,856          | 0 %             |
| Energy Total          | Electric & CW/HW | MJ                        | 955,287        | 777,895.5    | 18.6%                       | 688,791        | 16.4%           |

Figure 8: IES results: x-z plane (Dubai)

Figure 9: IES results: x-z plane (London)
5. Conclusions
The study demonstrates the potential saving on the annual space heating/cooling in two different climate zones (hot and cold climates). The same building has been selected to represent the space being heated/cooled at the two climate zones, the building was rotated into the prevailing wind direction and a courtyard has been introduced to act as a natural air well in order to increase the potential for outdoor natural ventilation. Then, roof configuration has been changed to reflect the assigned strategy in each climate zone. The results have been compared and the energy savings have been demonstrated using HAP software. It was shown that the HVAC load (heating) dropped to a total annual energy saving of 16.4 % in the cold climate area (London) while the cooling load dropped to an annual energy savings of 18.6 % in hot climate area (Dubai). This works suggests using passive cooling strategies at climates with warm winters such as Dubai to lower the use of air conditioning system at winter where the outdoor temperature and humidity values are good enough and there is a good potential for natural ventilation. The same applies to London summer where there is a good potential to replace the heating systems with natural ventilation.

References
[1] Tan, Z. & Deng, X. (2017). Assessment of Natural Ventilation Potential for Residential Buildings across Different Climate Zones in Australia. Atmosphere, vol. 8 (9), p. 177.
[2] ASHRAE Standard 62.2P; Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings. (2002). Atlanta, GA:ASHRAE.
[3] Green Building Guidelines, UAE. (2009). Dubai:Ministry of Public works, UAE.
[4] Macias, M., Gaona, J., Luxan, J. & Gomez, G. (2009). Low cost passive cooling system for social housing in dry hot climate. Energy and Buildings, vol. 41 (9), pp. 915-921.
[5] Alhamad, I., Alsleem, M. & Taleb, H. (2018). Natural ventilation potential strategies in warm winter climate zones — A case study of Dubai. 2018 Advances in Science and Engineering Technology International Conferences (ASET) [online]. AlAin UAE. IEEE.
[6] Ajibola, K. (1997). Ventilation of spaces in a warm, humid climate—Case study of some housing types. Renewable Energy, vol. 10 (1), pp. 61-70.
[7] R. Asbridge, R. Cohen, Probe 4: Queens Building, Building Services Journal 18 (4) (1996) 35–38, ISSN 0951-9270.
[8] BRECSU, The Queens Building De Montfort University—New Practice Final Report, vol. 102, Department of the Environment, 1997.
[9] Apple Park opens to employees in April. (2017). Retrieved from https://www.apple.com/newsroom/2017/02/apple-park-opens-to-employees-in-april.html
[10] BRECSU (2000). Energy Consumption Guide 19: Energy Use in Offices. Garston, Watford, UK, British Research Establishment Conservation Support Unit: 23 pages.
[11] Oropeza-Perez, I. & Østergaard, P. (2014). Energy saving potential of utilizing natural ventilation under warm conditions – A case study of Mexico. Applied Energy, vol. 130, pp. 20-32.
[12] Hamdani, M., Bekkouche, S., Benouaz, T., Belarbi, R. & Cherier, M. (2017). The Study Natural Ventilation by Using Buildings Windows: Case Study in a Hot Dry Climate, Ghardaia, Algeria. Energy Procedia, vol. 139, pp. 475-480.
[13] Emmerich, S., Dols, W., & Axley, J. (2001). Natural ventilation review and plan for design and analysis tools. US Dept. of Commerce, Technology Administration, National Institute of Standards and Technology.