Journal Home Page: https://sjes.univsul.edu.iq/

Research Article:

The Impact of Architectural Space Layout on Building Energy Performance: Heating and Cooling Demand of Typical Houses in Residential Projects in Sulaymaniyah City

Tablo Khalid Abdalla [1,a,*]
Amjad Muhammed Ali Qaradaghi [2,a]
[a] Department of Architecture Engineering, College of Engineering, University of Sulaimani, Kurdistan Region, Iraq

Article Information

Article History:
Received: July 9th, 2026
Accepted: September 19, 2026
Available online: December, 2026

Keywords:
Architectural space layout; Building energy performance; Heating demand; Cooling demand; Open-plan layout; Cellular-plan layout; Residential buildings; DesignBuilder; EnergyPlus.

About the Authors:
Corresponding author:
Tablo Khalid Abdalla
E-mail: tablo.abdalla@univsul.edu.iq
Researcher Involved:
Prof. Dr. Amjad Muhammed Ali Qaradaghi
E-mail: amjad.ali@univsul.edu.iq

DOI https://doi.org/10.17656/sjes.10232

Abstract

Architectural space layout is an important design parameter that affects heating and cooling demand, yet it has received less attention than other design variables, especially in hot-summer Mediterranean climates. This study examines how transforming open-plan layouts into cellular-plan layouts affects the heating and cooling demand of residential buildings in Sulaymaniyah City, Iraq. Three selected single-family houses were modelled using Design Builder/Energy Plus simulation engine. Two scenarios were developed to separate the effects of spatial subdivision. Scenario A tested spatial subdivision while retaining the baseline activity and operational assumptions. Scenario B combined spatial subdivision with realistic functional thermal zoning by assigning room-specific occupancy profiles. Annual heating and cooling loads were simulated under ideal HVAC conditions, followed by a prescribed ventilation-rate sensitivity analysis. Within the three investigated case models the results indicate controlled spatial subdivision produced only small and inconsistent thermal-demand changes under the tested assumptions. Under Scenario B, cellular layouts with function-specific operation reduced whole-building annual heating and cooling demand by 2.50–4.48%, although spatial subdivision was applied only to the ground floor. Heating demand decreased consistently in all three cases, whereas cooling demand changed only slightly, decreasing in two cases and increasing slightly in one. The prescribed ventilation condition further reduced cooling demand in both layouts without changing their relative thermal-demand ranking. Overall, the findings indicate that spatial subdivision alone produced limited thermal effects, whereas subdivision combined with function-specific operation produced larger changes in thermal demand.

Introduction

Buildings use a large share of global energy. UNEP and the Global Alliance for Buildings and Construction (GlobalABC) report that the buildings and construction sector accounted for about 32% of global energy in 2023 (UNEP & GlobalABC, 2025) [1]. In Iraq particularly, the building sector is responsible for 48% of energy use in Baghdad, with most of this energy being used for cooling and heating purposes [2]. In the Kurdistan Region of Iraq and notably in Sulaymaniyah city, the second-largest city of the region — increasing urbanization, improving living standards, and a growing reliance on mechanical heating and cooling systems have contributed to an increase in residential energy consumption. The Sulaymaniyah Governorate Sustainable Energy Action Plan [3] anticipates a strong rise in energy demand through to 2030, with the residential sector alone producing roughly 46% of total greenhouse gas emissions within the governorate. Against this backdrop, strategies to improve the energy efficiency of residential buildings are both economically and environmentally essential. Knowing the factors that affect building energy performance (BEP) is important for reducing energy consumption in buildings among them envelope insulation, glazing qualities, building orientation, compactness, and window-to-wall ratio [4]. Among the many design variables that affect residential energy use, spatial layout configuration the internal arrangement of rooms, the degree of spatial openness or subdivision has received comparatively limited experimental study. Most of the studies exist on energy-efficient design, pay more attention to geometry, envelopes, facade, material, atrium and shading systems. Alternatively, many researchers have been working on space layout through other design objectives including safety, logistics, efficiency, finance cost, occupant health and performance for many years, but rarely focused on space layout impact on energy performance [5]. Most existing literature on spatial layout and energy performance focuses primarily on office buildings in temperate European climates. Climate also limits how well these findings apply elsewhere. The balance between heating and cooling needs, the amount of solar gain, and the potential for natural ventilation all differ across temperate, hot-dry, and hot-summer Mediterranean climates. [6,7]. Over the past two decades, contemporary residential buildings in Sulaymaniyah city, Iraq have undergone a transformation from traditional courtyard houses to enclosed room, till the appearance of open-plan layouts influenced by modern design trends [8]. Studies investigating open-plan versus cellular configurations in hot-summer Mediterranean climate (Csa) and in residential settings, particularly in Iraq or the broader Kurdistan Region, are rare. This study uses a simulation-based approach to examine heating and cooling demand and to test its sensitivity to a prescribed ventilation rate, focusing on residential housing in Sulaymaniyah City. This study compares modelled heating and cooling demand between open-plan and cellular residential layouts. It applies controlled, function-specific operational conditions to three selected residential case models in Sulaymaniyah City. The objectives are:

1. To quantify how controlled spatial subdivision changes annual and peak heating and cooling loads.
2. To compare heating and cooling demand when cellular subdivision is combined with function-specific operation.
3. To compare the magnitude and direction of heating and cooling responses across the three case models.
4. To assess the sensitivity of heating and cooling demand to the prescribed ventilation condition.

The study aims to answer the following research questions:

RQ1. How does spatial subdivision change annual and peak heating and cooling loads when operational inputs are controlled?

RQ2. How do heating and cooling demands change when cellular subdivision is combined with function-specific occupancy and operational schedules?

RQ3. How do peak heating and cooling demands differ between open-plan and cellular-plan configurations with function-specific operation?

RQ4. How sensitive are the heating and cooling demands of the two configurations to the prescribed 2-ACH ventilation condition?

This study contributes a multiple-case residential assessment. It separates the thermal-demand effects of controlled spatial subdivision from the effects that appear when subdivision is combined with function-specific operation. Sulaymaniyah City, in northern Iraq, was chosen as the study context. It is classified as a hot-summer Mediterranean climate (Csa) under the Köppen–Geiger climate classification [9], as Figure 1 shows.

Space Layout and Energy Performance

2.1 Architectural Space Layout

The term "architectural space layout" refers to how spaces in a building are arranged and connected to each other [11]. Another definition describes layout as the process of turning functional needs into geometric relationships between rooms [12]. A third definition states that spatial organization affects circulation patterns and functional relationships between rooms [13]. It also affects how a building performs environmentally, through its impact on daylighting, ventilation, and thermal behavior [13]. One widely recognized distinction is between open-plan and cellular layouts. Open plans reduce internal walls which improve spatial flexibility, daylight distribution, and natural airflow [14]. Open-plan housing follows a principle of spatial integration which brings multiple residential zones together into one unified space. The open-plan concept can take different forms. Internal openness combines smaller rooms into larger, multifunctional spaces. The most extreme form of open plan is the "all-in-one" space, in which internal partitions are completely removed, allowing clear visibility across the entire space from any point. This layout aims to create a continuous, adaptable living environment, as shown in Figure 2 [15]. In contrast, partition walls are used in cellular layouts to create enclosed rooms, which in turn improves acoustic privacy, reduces noise transfer, and allows more personal control over thermal conditions, which might contribute to higher user satisfaction [16]. Though Partitioned space is a traditional approach to residential layout, this type of layout creates a more fixed and rigid spatial organization, which may reduce flexibility and make it less adaptable to change over time. However, reductions in partitioned spaces and adopting more open-plan configurations can enhance natural light penetration, air circulation, and resource efficiency, as shown in Figure 3 [17]. This study distinguishes these terms conceptually. Open-plan and cellular-plan describe architectural spatial configurations. Spatial integration refers to how physically and functionally connected spaces are. Thermal zoning means dividing the building model into separate thermal zones. Operational zoning means assigning function-specific occupancy, internal-gain, and conditioning profiles to those zones. Architectural subdivision, thermal zoning, and function-specific operation are related, but they are not the same thing.

2.2 Space Layouts in Sulaymaniyah City Residential Housing

During the early development of Sulaymaniyah city, residential layouts were strongly influenced by traditional Kurdish houses, where courtyard-based layouts and rooms were arranged around the central courtyard and connected by narrow corridors [8]. These traditional houses had high spatial depth and low integration, where rooms were more compartmentalized [18]. From the 1960s onward, Sulaymaniyah city experienced rapid urban growth, The traditional courtyard houses were gradually replaced by new homes with detached and semi-detached typologies, which had in closed rooms connected by corridors [8,18]. After 2003, Sulaymaniyah city experienced rapid urban growth. This growth led to significant urban expansion and the construction of new residential developments [19,20]. Changing lifestyles and modern construction practices have encouraged the use of open-plan layouts, especially in living, dining, and kitchen areas [21]. Figure 4 shows a Typical plan of German Village houses back in 2007, showing partially open areas in the ground floor plan between Dining area and guest room.

1.3 Building Energy Performance (BEP)

According to CIBSE Guides Energy efficiency in buildings refers to providing essential services such as heating, cooling, ventilation, lighting and hot water while using the least possible amount of energy and maintaining occupant comfort and indoor environmental quality [22], Energy performance is evaluated by comparing the useful output of a building system such as heating, cooling, or ventilation and the amount of energy required to provide that output. Energy performance is influenced by building design characteristics, climate, equipment type, and operating strategies [23]. Building energy performance (BEP) it is defined as the actual energy use and operational efficiency of a building during its use, reflecting how well it meets occupant needs. The factors affecting BEP can be grouped into two main categories. Physical factors which include climate, building envelopes, building services and energy systems such as HVAC, lighting, and appliances, as well as operation and maintenance practices. Human-influenced factors primarily involve occupant activities and behavior, which can significantly impact on energy use [24]. For residential buildings specifically, the most important factors include the type and efficiency of air-conditioning systems, as central or oversized units can increase energy use, while high-efficiency systems reduce it, building size and the number of occupants also affect consumption since larger homes and higher occupancy levels increase cooling loads and internal heat gains. In addition, occupant behavior, such as thermostat settings and maintenance practice, plays an important role in energy use. Seasonal changes, especially during the peak summer months, increase cooling demand and, as a result, overall energy consumption. Finally, technological factors such as the use of energy-efficient appliances, smart controls, and modern compressor systems can help reduce overall residential energy demand [25].

1.4 Energy Indicators

Energy indicators can be classified based on three main aspects: the type of energy end-use, the assessment period, and the system boundary. These aspects are explained below:

Energy end-used in buildings includes activities such as space heating, space cooling, water heating, lighting, ventilation, and electricity used for appliances. The assessment period refers to the time used to evaluate energy consumptions. It can be based on annual performance or over shorter periods, such as a single summer or winter day. The choice of assessment period depends on the climate characteristics of a specific location. System boundaries define the area included for BEP assessment. It may be limited to the conditioned space of a building or housing unit, the entire building site, or extend beyond the site. Based on these boundaries, the energy inputs are categorized as energy demand (or energy needs), final energy, and primary energy [5]. This study is limited to energy demand at the zone level. It calculates heating and cooling thermal demand using an Ideal Loads system. Final energy consumption and primary energy fall outside the scope of the simulation.

1.5 Residential Energy Use Patterns in Sulaymaniyah City

According to the Sulaymaniyah Governorate Sustainable Energy Action Plan (SEAP), energy demand is expected to increase across the residential, industrial, transportation, public services, and government sectors by 2030. It also projects that the electricity deficit will increase from about 3 billion

USD to 4.86 billion USD if current trends continue. The residential sector, responsible for nearly 46% of total emissions, making it the focus of energy reduction efforts. [3], Energy use in Iraq shows a clear difference between the north and south region of the country. In the north of Iraq, winters are colder which leads to higher heating demand; therefore, energy use increases during winter months in addition to summer cooling needs. In contrast, the south of Iraq has a much hotter climate in both summer and winter, which makes cooling the primary energy use throughout the year [26].

1.6 Architectural Space Layout impact on BEP

Architectural space layout can affect residential thermal performance through several physical and operational mechanisms that interact with each other. More enclosed layouts can support separate thermal zoning, which lets spaces be conditioned according to their own operational needs and can potentially reduce heating and cooling demand. In contrast, open layouts require energy to larger room volumes at once which in turn makes indoor temperature balance more difficult, leading to increasing energy demand [27]. Previous ventilation research shows that spatial configuration can shape airflow paths. Connected spaces with well-placed openings may support airflow driven by pressure differences, while internal partitions can block or redirect that airflow [28]. Beyond physical performance, architectural layout also affects occupants living in the house, which has a real impact on energy consumption [29].

1.7 Layout Parameters Affecting BEP

The literature identifies several layout parameters that affect building energy performance. Building orientation affects how much sunlight a building receives and how well natural ventilation works, which changes heating and cooling energy use [30]. Compact building shapes improve energy efficiency, because they have less surface exposed to the outside and this reduces heat transfer [31,32]. The window-to-wall ratio affects daylight and thermal performance, and the best ratio depends on orientation, climate, glazing type, and shading [33,34]. Shallow floor plans let daylight reach further inside and reduce lighting energy use, while deeper plans rely more on artificial lighting and HVAC [35]. A way improves thermal zoning and can cut HVAC energy use by 15–30% is by grouping frequently used spaces together, and using low-occupancy spaces as thermal buffers, [13]. Higher ceilings can help daylight and ventilation, but they may also increase heating and cooling loads due to larger air volumes [36,37]. Well-designed atriums and courtyards can improve daylighting and ventilation, especially in hot climates where stack ventilation improves thermal comfort [29,39]. Evidence from office-building studies shows that open-plan layouts can improve daylight distribution and spatial flexibility, while cellular configurations can support more differentiated thermal zoning and environmental control [6]. These findings, however, do not transfer directly to residential buildings, because occupancy patterns, internal gains, conditioning schedules, and space-use characteristics differ between the two building types. The placement of stairs and circulation cores can act as thermal buffers and improve overall energy efficiency [40]. Finally, the core to perimeter ratio matters. Perimeter areas benefit from daylight and ventilation, while core zones depend more on artificial lighting and mechanical systems [41]. Together, these parameters shape a building's thermal behavior, daylighting performance, ventilation potential, and overall energy consumption [38]. The effect of spatial layout on heating and cooling demand likely comes from several mechanisms acting together, not from partition geometry alone. Spatial subdivision can change thermal zoning and conditioning patterns, and it can also affect airflow paths and occupant-related energy use [27–29]. These mechanisms can interact with envelope characteristics such as glazing area, orientation, solar exposure, and external surface area, all of which influence heating and cooling demand [30–34]. Differences between open-plan and cellular configurations should therefore be read alongside their physical and operational assumptions. When the external envelope stays the same, adding internal partitions does not change the building-level external surface-to-volume ratio. Instead, the partitions add internal surfaces and redistribute heat transfer between the resulting thermal zones [42]. This distinction matters for separating the geometric effect of spatial subdivision from the effects of thermal zoning and function-specific room operation.

2.8 Literature Gap and Research Positioning

Existing research shows that spatial configuration can affect building thermal performance through thermal zoning, occupancy and conditioning schedules, internal gains, airflow connectivity, and interactions with building-envelope characteristics. However, most of the available evidence on open and cellular configurations comes from office buildings and/or climates different from Sulaymaniyah [6,7]. It is therefore unclear how far these relationships apply to single-family residential buildings in Sulaymaniyah City's climate. This study fills that gap by focusing on residential buildings in a hot-summer Mediterranean climate (Csa), through a comparative simulation of three selected residential house models. It distinguishes between spatial subdivision under controlled operational assumptions (Scenario A) and spatial subdivision combined with function-specific operation (Scenario B), then examines how these two conditions affect simulated heating and cooling demand within the residential and climatic context.

Methodology

3.1 Research Design and Case Study Selection

This study uses a quantitative comparative computational experiment within a multiple-case-study design. The initial sampling frame consisted of thirty-three residential projects in Sulaymaniyah City. Each project was evaluated against eight predefined eligibility criteria: location within Sulaymaniyah City, single-family residential function, row-house typology, plot area of 150–200 m², two-story configuration, existing open-plan layout, construction period between 2015 and 2025, and medium-income housing category. Projects that did not satisfy these requirements were excluded. Following screening, three projects, Aro City, Deru City, and Qaiwan City were selected for detailed simulation. The selected houses span a built-area range of 180.58–243.77 m² for both floors. Of the thirty-three projects screened, thirty failed to satisfy one or more eligibility criteria and were excluded. Therefore, the three projects that satisfied all eight criteria constituted the final case-study sample to provide variation in built areas, surface-to-volume ratio, window-to-wall ratio, and skylight area. The complete thirty-three project screening matrix was kept as part of the research dataset. Because of manuscript-length limits, the screening outcome is reported numerically in the text, and the eligibility criteria of the three selected cases are summarized in Table 1 and each case study characteristics are presented in Table 2. The experimental component compares simulated heating and cooling demand between open-plan and cellular-plan configurations under control and function-specific operational conditions, while the multiple-case design enables comparison across three selected residential projects. The unit of sampling was the residential housing project. The unit of modelling was one selected house model from each of the three selected projects. The unit of analysis was the conditioned house for annual and peak heating and cooling loads. Zone-level outputs were used only for the comparison of zone-average indoor air temperatures. For comparative intensity calculations, each case's original architectural conditioned floor area was retained as a fixed reference denominator for both configurations. DesignBuilder-reported net zone floor area decreased slightly after subdivision. This happened because the added partitions occupied some floor footprints, as reported in Table 5. The same conditioned-floor-area denominator was used consistently for all heating- and cooling-intensity values reported in kWh/m². Each house model was evaluated under its corresponding open-plan and cellular-plan configurations. For comparative simulation, the models were standardized to a southwest-facing front-façade azimuth of 210°. All three selected case-study houses were originally southwest-oriented. The common 210° simulation orientation therefore matched their original project orientation, rather than representing a reorientation of the houses. Surface azimuth was defined clockwise from north (0° = north, 90° = east, 180° = south, 270° = west). Therefore, 210° corresponds to a southwest-facing façade. Southwest was the largest single orientation category among the projects surveyed (145 of 311 houses), as shown in Table 3 and Figure 5. Standardizing the orientation provided a consistent solar-exposure condition for comparing the open- and cellular-plan configurations. The results are therefore interpreted specifically for the tested southwest orientation, rather than as orientation-independent effects. Model geometry and principal floor dimensions were developed from the available architectural drawings and carefully checked before simulation. Nominal household size of five people was assumed for the case-study definition, while zone-level occupancy in the simulations was represented using the DesignBuilder occupancy densities and schedules specified for each scenario. Building construction materials, Lighting and equipment inputs were assigned according to the activity profiles described in Section 3.3. summarized in Table 6. The simulations were performed in DesignBuilder using its integrated EnergyPlus 9.4.0 simulation engine. The whole methodology procedure is illustrated in Figure 6.

3.2 Spatial Layout Transformation Protocol

The transformation from open-plan to cellular-plan layout followed a predefined design protocol applied consistently across all three case studies. A maximum added internal-wall ratio of 15% was adopted as a study-specific design constraint to prevent excessive modification of the original plans. The actual added-wall ratios ranged from 7.74% to 10.10% This value was not taken from a literature-based threshold. The purpose of this limit was to constrain the extent of spatial modification and avoid excessive partitioning of the original ground-floor layouts. The added wall ratio was calculated relative to the total internal-wall area of the original ground-floor configuration, as follows:

Added Wall Ratio (%) = (Added Internal Partition Wall Area / Original Ground-Floor Internal Wall Area) × 100

Wall areas were determined from the architectural floor plans. This was done by summing the lengths of the relevant internal wall segments, then multiplying the total wall length by the corresponding wall height:

$L\_total = L_1 + L_2 + L_3 + \dots + L_n$

$A\_wall = L\_wall \times H\_wall$

The added partitions were maintained at below 15% of the original ground-floor internal-wall area in each case, as shown in Table 4. New partition walls were modelled as 100-mm-thick, non-load-bearing concrete-block elements. Internal door openings measuring 1000 mm × 2100 mm (width × height) were provided where required for circulation. The internal doors between subdivided spaces were modelled as closed during the simulations. A fixed internal window measuring 1700 mm × 1700 mm (width × height) was used across all three case studies, The purpose was daylight access to newly enclosed rooms. No explicit interzone air-mixing object was assigned between adjacent thermal zones. As a result, air exchange between neighboring zones through internal openings was not modelled. Conductive heat transfer through the interzone partitions and closed internal doors, however, remained represented. The layout change is applied to ground floor plans only. The first floor, which is already cellular layout in the cases, was kept the same in both configurations. This reflects typical practice that opens plan layout mainly exists in the ground floor plan of the houses. The plans floors are presented in Table 4, and a building section showing the materials are shown in Figure 7.

3.3 Simulation Scenarios

Two scenarios were defined to systematically assess the effects of spatial reconfiguration:

Scenario A — Spatial Subdivision under Controlled Operation: Partition walls were added to subdivide the original open-plan ground floor into a cellular configuration, while giving the same activity profile across the newly created spaces. Scenario A kept the same baseline activity as the original open-plan across the subdivided spaces. Quantitative verification from the simulation inputs, however, showed small changes in annual internal gains following subdivision, because subdivision altered the modeled net zone areas. as reported in Table 5. Scenario A is therefore interpreted as a controlled operational comparison.

Scenario B — Spatial Subdivision with Function-Specific Operation: The cellular configuration from Scenario A was taken, but each room was now assigned a residential activity profile according to its function — living, dining, guest, and kitchen spaces. These profiles include function-specific occupancy densities and schedules. Scenario B therefore represents spatial subdivision combined with function-specific operation, rather than an isolated geometric effect only. A variable-control matrix for both simulation scenarios is provided in Table 5, summarizing the variables controlled and modified across the simulation configurations. Scenario A keeps baseline operational assumptions while changing spatial subdivision and thermal zoning, whereas Scenario B keeps the same cellular geometry but introduces function-specific occupancy, lighting, equipment, and conditioning profiles. Annual internal sensible gains are reported to make these operational differences clear.

3.4 Simulation Settings and Weather Data

All simulations were run in DesignBuilder using the EnergyPlus engine over a full year (8,760 h). Heating and cooling loads were calculated using the Ideal Loads Air System, an ideal HVAC method that determines each zone's heating and cooling thermal energy demand without modelling a specific mechanical system. The principal building envelope properties, operational assumptions, and simulation settings applied consistently across the case-study models are summarized in Table 6. Each enclosed room was represented as an individual EnergyPlus thermal zone. In the original open-plan configurations, the connected principal ground-floor spaces were represented according to their original open-plan zoning, whereas cellular subdivision introduced additional thermal zones for the newly enclosed rooms, the plan zones are shown in Table 4. Scenario A and Scenario B used identical cellular thermal-zone topology. Within the principal ground-floor open-plan area subject to subdivision, one original thermal zone was subdivided into four thermal zones in each of the three case studies (Aro City, Deru City, and Qaiwan City). Existing enclosed spaces, including those outside the transformed principal ground-floor area, retained their original thermal-zone representation. Only the ground-floor principal open-plan area was modified during the layout transformation. An Ideal Loads Air System was assigned to each conditioned zone; no conventional HVAC air-loop system was modelled. This approach was used to isolate the thermal-demand effects of the building envelope and spatial configuration from the efficiency and operational characteristics of specific HVAC equipment. Annual and peak heating and cooling demand was reported for the conditioned house. The dependent variables evaluated in this study were annual space-heating and cooling thermal demand, peak heating and cooling loads, and the change in heating and cooling demand under the prescribed ventilation conditions. The simulation boundary of this study is therefore limited to zone-level heating and cooling thermal demand. The reported values do not represent whole-building final energy consumption, because HVAC system efficiency, fan and pump electricity, appliance electricity, domestic hot-water energy, and other operational energy uses fall outside the simulation boundary. This approach allows the comparison to focus on thermal demand independently of the efficiency characteristics of a specific HVAC system. The same temperature-control settings were applied to all conditioned zones: the heating setpoint and setback temperatures were 21°C and 16°C, respectively, while the cooling setpoint and setback temperatures were 24°C and 26°C.

Simulations used a Typical Meteorological Year (TMYx) weather file for Sulaymaniyah city, Iraq (Station 406230; 35.55° N, 45.45° E), from Climate.OneBuilding.org. The data is based on NCEI ISD and ERA5 records between 2011–2025. It provides hourly climate data, including dry-bulb temperatures, as shown in **Figure 8.** Model development followed a consistent quality-control workflow: geometry preparation from the architectural drawings, assignment of envelope constructions and thermal zones, application of occupancy and operational schedules, verification of scenario-specific input differences, and review of annual, peak, and monthly simulation outputs for consistency. The study is therefore treated as a controlled comparative simulation, rather than as a prediction of actual household energy consumption.

3.5 Prescribed Ventilation-Rate Sensitivity Analysis

A separate sensitivity analysis was conducted to evaluate the effect of a prescribed ventilation rate on heating and cooling demand, for the open- and cellular-plan configurations under Scenario B. Ventilation was imposed at 2 ACH during occupied hours when the outdoor temperature was between 18°C and 32°C, with a ΔT control of 0°C. The 18–32°C range was adopted as a study-defined operational control adapted to the climatic conditions of Sulaymaniyah City. Because the airflow rate was prescribed rather than calculated from wind pressure, buoyancy, opening characteristics, or interzone airflow paths, this analysis does not predict actual airflow or cross-ventilation effectiveness. It therefore evaluates only the thermal-load response of the two configurations under the specified ventilation condition.

Results and Analysis

4.1 Scenario A – Spatial Subdivision (Baseline Case)

Table 7 shows the total load intensity for the three case studies under Scenario A, which evaluates spatial subdivision and the associated thermal-zone reconfiguration while retaining the baseline operational assumptions. The results show small and inconsistent changes, which can be analyzed as: spatial subdivision under the controlled Scenario A assumptions did not produce a consistent thermal-load reduction. Across the three cases, the Scenario A differences range from −0.04 kWh/m² in Deru City to 1.32 kWh/m² in Aro City — values that are small relative to each case study's baseline open-plan load. Aro City recorded the largest reduction under Scenario A at 1.32 kWh/m², but this is still smaller than its Scenario B improvement of 3.70 kWh/m². Qaiwan City follows a similar pattern, Scenario A difference of 0.69 kWh/m² compared to 2.27 kWh/m² in Scenario B. Finally, Deru City records −0.04 kWh/m² which is a near-zero difference in Scenario A. The negative value is worth noting and indicates the cellular-plan configuration increased total load intensity. The contrast between the Scenario A and Scenario B columns across all three cases is the most important finding of this table. The larger differences observed in Scenario B indicate that the combined effect of spatial subdivision and function-specific operation has a greater influence on thermal demand than spatial subdivision alone. Scenario A, which was a methodological control, produced small and inconsistent results with little thermal benefit.

4.2 Heating Load Analysis (Scenario B)

As shown in Table 8, annual heating intensity in the original open-plan configurations ranged from 32.31 to 36.66 kWh/m². Aro City recorded the highest heating intensity, at 36.66 kWh/m², while Deru City and Qaiwan City recorded similar values of 32.31 and 32.34 kWh/m², respectively. Because the three case models differ simultaneously in several physical characteristics, these differences cannot be attributed to any individual building parameter from the present simulations. **Table 9 and Figure 9** confirm that cellular plan layouts reduce annual heating load intensity in all three cases. The reductions range from 1.58 kWh/m² in Qaiwan City to 2.78 kWh/m² in Aro City, nearly 5–8% decrease from the original open plan. Aro City showed the largest absolute reduction in heating intensity (2.78 kWh/m²), whereas Deru City showed the largest percentage reduction (7.69%); however, because thermal zoning and function-specific operation change simultaneously under Scenario B, the reduction cannot be attributed to the partition walls alone. Qaiwan City shows a smaller reduction. Table 10 and Figure 10 present the whole building with peak heating loads. Consistent with the annual heating results, peak heating load decreased under the cellular configuration in all three cases. Aro City decreased from 12.21 to 11.83 kW (0.38 kW), Deru City from 12.90 to 12.55 kW (0.35 kW), and Qaiwan City from 16.23 to 15.89 kW (0.34 kW), with Aro City showing the largest absolute decrease. The similar trend in annual and peak loads indicates that the cellular configurations were associated with lower heating loads in all three investigated cases under Scenario B.

4.3 Cooling Load Analysis (Scenario B)

Table 11 shows greater variation in baseline cooling intensity than in heating intensity, ranging from 29.86 kWh/m² in Deru City to 45.81 kWh/m² in Aro City. Aro City recorded the highest cooling intensity, while Deru City recorded the lowest. Because the three cases differ simultaneously in floor area, WWR, surface-to-volume ratio, skylight area, and other physical characteristics, the present three-case comparison does not isolate the contribution of any individual parameter to these differences. Qaiwan City, despite having the lowest WWR (21.06%), recorded the second highest annual cooling load and a relatively high cooling intensity. This response may be associated with the combined influence of its larger floor area, skylight area, solar exposure, and other case-specific characteristics. Deru City, with the highest surface-to-volume ratio (0.71) and a moderate skylight area, has the lowest cooling intensity.

Table 12 and Figure 11 compare annual cooling performance between the original open-plan and cellular-plan. The results show that layout change produced small shifts in annual cooling demand. Aro City and Qaiwan City showed small reductions in cooling intensity, by 0.92 kWh/m² and 0.69 kWh/m², while Deru City showed a small increase of 0.94 kWh/m², meaning the cellular layout increased cooling demand slightly under Scenario B. These results indicate that the effect on annual cooling demand was small and case-dependent within the three investigated models. **Table 13** and Figure 12 present peak cooling loads for both plan layouts. Unlike the annual cooling results, all three cases showed an increase in peak cooling load under the cellular configuration. Aro City increased from 13.87 to 14.02 kW (an increase of 0.15 kW), Deru City from 9.25 to 10.11 kW (0.86 kW), and Qaiwan City from 18.20 to 18.80 kW (0.60 kW). These results indicate higher whole-building peak cooling load in the cellular configurations under the combined Scenario B conditions

4.4 Combined annual heating and cooling thermal demand

Table 14 and Figure 13 present heating and cooling results into total annual thermal demand. The table and figures show lower combined annual heating and cooling thermal demand for the cellular configurations under Scenario B. In all three cases, cellular layouts lower the combined annual heating and cooling thermal demand: 4.48% in Aro City, 2.96% in Qaiwan City, and 2.50% in Deru City, and this result means heating-load reductions outweigh cooling losses. Aro City showed the largest absolute reduction, at 667.84 kWh (4.48%), while Deru City showed a reduction of 325.02 kWh (2.50%). These results were obtained under Ideal Loads conditions, with both mechanical ventilation and the prescribed ventilation condition disabled.

4.5 Relationship Between Outdoor Climate Conditions and Thermal Energy Demand

Monthly heating and cooling demand followed the outdoor climate conditions in the weather file. Peak heating loads in winter (December–February), when average outdoor temperatures ranged from about 5°C to 8°C. As temperatures increase in spring, heating demand dropped, while a small amount of cooling demand appeared in March and April. Cooling loads increase from May onward, peaking in July and August, when average temperatures reached 32°C and summer peak load of 44°C. During these months, heating demand was small across all cases. This seasonal pattern is consistent with the expected climatic relationship between outdoor temperature and heating and cooling demand, and therefore provides a plausibility check on the simulated seasonal response, as shown in Tables 15 and 16. The negative cooling values in the tables follow the simulation's sign convention, in which cooling represents thermal energy removed from the zone rather than negative energy consumption.

4.6 Thermostat-Setpoint Sensitivity Analysis

A thermostat-setpoint sensitivity analysis was conducted through 24 additional annual simulations. Heating and cooling were tested separately by varying their respective original setpoint settings by ±1°C while keeping the other simulation assumptions unchanged. For the heating sensitivity test, Scenario B maintained lower heating demand across all tested settings, with savings ranging from 4.36% to 8.19%. For the cooling sensitivity test, Aro City and Qaiwan City consistently maintained lower cooling demand under Scenario B, whereas Deru City consistently maintained higher cooling demand. Although the magnitude of the differences varied with setpoint changes, the direction of the open–cellular comparison therefore remained stable across both sensitivity tests, as shown in Table 19.

4.7 Prescribed Ventilation-Rate Sensitivity

Table 17 shows that the prescribed ventilation condition reduced cooling loads in both open- and cellular-plan configurations, across all three cases, with reductions ranging from 2.70% to 3.96%. The cellular configurations showed slightly greater percentage reductions than their corresponding open-plan configurations, with Aro City showing the largest difference (3.68% for the open plan and 3.96% for the cellular plan). Deru City and Qaiwan City followed the same trend but with smaller differences. These results represent the thermal-load response to the prescribed 2-ACH ventilation condition, and do not indicate differences in actual airflow or cross-ventilation effectiveness between the layouts. Table 17 also shows that the prescribed ventilation condition had a very small effect on annual heating loads. The changes ranged from 0.07 kWh for the Deru City cellular configuration to 7.44 kWh for the Aro City open-plan configuration, which is a small value relative to the corresponding annual heating loads. This limited effect is consistent with the applied control settings, under which ventilation was disabled when the outdoor temperature fell below 18°C.

The results presented in Table 18 and Figure 14 show that, with the prescribed ventilation condition included, transforming the open-plan configuration to the cellular configuration reduced total annual heating and cooling demand in all three cases. Aro City showed the largest reduction, at 687.48 kWh (4.71%), followed by Qaiwan City at 571.48 kWh (3.11%) and Deru City at 351.96 kWh (2.73%). In the Deru City cellular configuration, cooling demand increased slightly, but this increase was outweighed by the reduction in heating demand. Overall, the prescribed ventilation condition reduced cooling demand in both configurations, without changing the relative ranking of the open- and cellular-plan configurations under the tested simulation assumptions.

4.8 Zone-Average Air Temperature Comparison between Open and Cellular Plans

Figure 15 compares the zone average indoor air temperatures of the open- and cellular-plan configurations on January 15 and July 15, representing heating and cooling periods, respectively. The open-plan configurations show more uniform zone-average temperatures across the connected ground-floor spaces, whereas the cellular configurations show greater variation among the separately defined rooms. These differences should be interpreted as variations in zone-average air temperature, not as evidence of local airflow or heat-movement patterns. EnergyPlus assumes well-mixed air within each thermal zone and does not resolve spatial airflow distribution within zones. Temperature maps are therefore used only to compare the simulated thermal conditions of the defined zones, not to evaluate airflow or cross-ventilation behavior.

5. Discussion

5.1 Geometric vs. Functional Effects: An Essential Distinction

Scenario A shows that spatial subdivision under controlled operational assumptions produces only small and inconsistent changes in thermal demand. Because the external envelope remained unchanged, subdivision did not reduce the building-level surface-to-volume ratio; heat transfer through internal partitions represents redistribution between conditioned zones, rather than additional heat loss from the building. In contrast, the larger differences observed in Scenario B occur when the cellular configuration is combined with function-specific occupancy, internal gains, and conditioning profiles. These Scenario B differences should therefore be interpreted as the combined effect of spatial subdivision and function-specific operation, rather than as an effect of partition geometry or thermal zoning alone. The zone-average temperature maps presented in Section 4.8 support this interpretation. The open-plan configurations showed more uniform zone-average temperatures across the connected ground-floor spaces, whereas the cellular configuration showed greater variation among separately defined rooms. These differences represent simulated zone-average thermal conditions and should not be read as evidence of interzone airflow or air-mixing behavior. The contrast between Scenarios A and B indicates that the principal thermal-demand response was not produced by spatial subdivision alone, but by the interaction between subdivision, thermal zoning, and function-specific operation. This interpretation aligns with previous studies showing that spatial configuration may affect energy performance through operational zoning, differentiated conditioning schedules, and occupant-related internal gains, rather than through partition geometry alone [6,13,27]. However, much of the existing evidence comes from office buildings or climatic contexts different from Sulaymaniyah city. The present results therefore extend this discussion to selected single-family residential cases in a hot-summer Mediterranean climate.

5.2 Heating vs. Cooling: Seasonal Asymmetry

Heating and cooling loads respond differently to layout change, and this seasonal asymmetry is important when interpreting the thermal-demand effects of cellular-plan configurations. The observed heating reductions may be associated with the combined effects of cellular thermal zoning and function-specific operational profiles. Because these factors change simultaneously in Scenario B, their individual contributions cannot be isolated from the present simulations. Deru City's increase in annual cooling demand further shows that the response to cellular subdivision was case-dependent. Because several operational and physical characteristics differ simultaneously between the investigated configurations and cases, the present simulations do not provide sufficient heat-balance decomposition to attribute this increase to a specific parameter, such as partition area, room size, skylight area, or solar exposure. The thermal-demand benefit associated with the Scenario B cellular configurations was not universal and depended on the combined spatial and operational conditions of each case. Although Scenario B reduced total annual heating and cooling demand in all three cases, the whole-building reductions of approximately 2.5–4.5% are relatively modest. This is partly because the first floor was not modified, which diluted the reduction at the whole-building level. These differences may still be relevant when accumulated over the operational life of a dwelling, but they should not be interpreted as large energy savings.

5.3 Annual Demand versus Peak Cooling Load

Although Scenario B reduced total annual heating and cooling demand in all three cases, peak cooling demand increased in every cellular configuration. This is not contradictory. Annual cooling demand represents the accumulation of cooling requirements over the year, whereas peak cooling load represents the maximum cooling requirement at a particular simulation timestep. Function-specific zoning and operational schedules may therefore reduce cooling requirements over many hours, while a higher coincident cooling requirement can still occur during a limited peak period. This distinction has an important design implication: lower annual thermal demand does not necessarily mean lower required cooling capacity. Higher peak cooling loads may require greater HVAC sizing and could increase short-duration electrical demand when translated into real mechanical systems. This indicates that a configuration associated with lower annual thermal demand may still require a higher peak cooling capacity, highlighting the distinction between annual energy demand and system sizing requirements. The cellular configurations investigated here therefore present a trade-off, between lower annual thermal demand under Scenario B and higher peak cooling requirements.

5.4 Prescribed Ventilation-Rate Sensitivity

The prescribed ventilation-rate sensitivity analysis showed that applying 2 ACH, under the specified temperature and occupancy controls, reduced cooling demand in both open- and cellular-plan configurations. The reduction ranged from 2.70% to 3.96% across the investigated cases, while the effect on annual heating demand was very small, because ventilation was disabled below an outdoor temperature of 18°C. Slight differences in cooling-load reductions were observed between the two layout configurations. However, these differences should not be interpreted as evidence of differences in ventilation effectiveness or cross-ventilation performance, because airflow was prescribed rather than calculated from wind pressure, buoyancy, opening characteristics, or interzone airflow paths.

5.5 Limitations

1- The layout change was applied to the ground floor only; modifying the first floor as well would likely produce different and possibly larger energy effects.

2- The study uses an Ideal Loads system rather than a real HVAC model, so actual results may be different depending on system type, efficiency, and controls.

3- The study focuses only on thermal demand and the Prescribed 2-ACH Ventilation Condition, other important factors such as daylight, acoustics, construction cost, and occupant satisfaction were not assessed.

4- The three selected case studies do not constitute a statistically representative sample of residential development in Sulaymaniyah City and cannot capture the full range of housing typologies.

5- Ventilation was represented using a prescribed air-change rate; therefore, actual airflow patterns and cross-ventilation effectiveness were outside the scope of the simulation.

6- All models were evaluated at a fixed southwest orientation (210°); therefore, the interaction between spatial layout and alternative building orientations was not examined.

6. Conclusions

This study has investigated the thermal demand implications of open-plan versus cellular-plan spatial configurations in three residential buildings in Sulaymaniyah City, Iraq, using DesignBuilder/EnergyPlus dynamic building energy simulation. Through a two-scenario methodological design, the study evaluated spatial subdivision under controlled operation (Scenario A) and spatial subdivision combined with function-specific operation (Scenario B). The following conclusions are drawn:

(1) Under Scenario A, spatial subdivision under controlled operational assumptions produced only small and inconsistent changes in heating and cooling demand across the three simulated cases. Therefore, under the tested modelling assumptions, subdivision alone did not produce a consistent thermal-demand benefit within the three southwest-oriented house models investigated.

(2) Spatial subdivision combined with function-specific operation resulted in lower combined annual heating and cooling thermal demand under Scenario B. Across the three case studies, total annual heating and cooling demand decreased by 2.50–4.48%, with the reduction in heating demand as the primary contributor.

(3) Heating load reductions under Scenario B are consistent. The cellular plan configuration reduced annual heating intensity, with reductions in peak heating load in all three cases.

(4) Cooling-demand responses were case-dependent. Two of the three cases showed modest reductions in annual cooling intensity, whereas Deru City showed an increase under the cellular configuration. Because multiple physical and operational parameters differ simultaneously, the present simulations do not isolate the cause of this case-specific cooling response. However, peak cooling load increased in all three cellular configurations, indicating that reductions in annual thermal demand do not necessarily correspond to lower peak cooling requirements.

(5) The prescribed 2-ACH ventilation condition reduced cooling demand across all investigated configurations, while having very small influence on heating demand.

(6) Within the three southwest-oriented house models investigated, the findings indicate that spatial layout and function-specific operation can influence simulated heating and cooling demand. These case-specific results may inform architectural design considerations for similar residential configurations in Sulaymaniyah City. Broader generalization, however, requires testing across a larger and more diverse sample of residential buildings, orientations, and operational conditions.

References

[1] United Nations Environment Programme (UNEP), Global Status Report for Buildings and Construction 2024/2025: Not just another brick in the wall – The solutions exist. Scaling them will build on progress and cut emissions fast. 2025, Paris: United Nations Environment Programme. https://doi.org/10.59117/20.500.11822/47214

[2] Abbood, A.W., Al-Obaidi, K.M., Awang, H., and Abdul Rahman, A.M., Achieving energy efficiency through industrialized building system for residential buildings in Iraq. International Journal of Sustainable Built Environment, 2015. 4(1):p.78–90. https://doi.org/10.1016/j.ijsbe.2015.02.002

[3] UNDP–LADP, Kaassamani, O., and Ali, A., Iraq Sulaymaneyah-Governorate SEAP 2. 2025.

[4] Olu-Ajayi, R., Alaka, H., Egwim, C., and Grishikashvili, K., Comprehensive Analysis of Influencing Factors on Building Energy Performance and Strategic Insights for Sustainable Development: A Systematic Literature Review. Sustainability, 2024. 16(12): p. 5170. https://doi.org/10.3390/su16125170

[5] Du, T., Space layout and energy performance: Parametric optimisation of space layout for the energy performance of office buildings. A+BE | Architecture and the Built Environment, 2021. 11(15): p. 1–248. https://doi.org/10.7480/abe.2021.15.5972

[6] Shahzad, S., Brennan, J., Theodossopoulos, D., Hughes, B., and Calautit, J.K., Energy and comfort in contemporary open plan and traditional personal offices. Applied Energy, 2017. 185(Part 2): p. 1542–1555. https://doi.org/ https://doi.org/10.1016/j.apenergy.2016.02.100

[7] Cao, J., Zhang, H., Savov, A., Hall, D.M., and Dillenburger, B., Energy-aware design: Predicting building performance from layout graphs. Proceedings of the 2022 European Conference on Computing in Construction, 2022: p. 130–137. https://doi.org/10.35490/EC3.2022.210

[8] Abdullah, W.S., and Abdullah, A.A., Genotypical Change of Traditional Houses in Sulaymaniyah City. The Scientific Journal of Cihan University–Sulaimaniya, 2024. 8(1): p. 1–23. https://doi.org/10.25098/8.1.23

[9] Kottek, M., Grieser, J., Beck, C., Rudolf, B., and Rubel, F., World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, 2006. 15(3): p. 259–263. https://doi.org/10.1127/0941-2948/2006/0130

[10] Beck, H.E., McVicar, T.R., Vergopolan, N., Berg, A., Lutsko, N.J., Dufour, A., Zeng, Z., Jiang, X., van Dijk, A.I.J.M., and Miralles, D.G., High-resolution (1 km) Köppen-Geiger maps for 1901–2099 based on constrained CMIP6 projections. ScientificData,2023.10:p.724. https://doi.org/10.1038/s41597-023-02549-6

[11] Hillier, B., and Hanson, J., The Social Logic of Space. 1984, Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511597237

[12] Lobos, D., and Donath, D., The problem of space layout in architecture: A survey and reflections. Arquitetura Revista, 2010. 6(2): p. 136–161. https://doi.org/10.4013/arq.2010.62.05

[13] Ching, F.D.K., and Shapiro, I.M., Green Building Illustrated. 2 ed. 2021, Hoboken, NJ: John Wiley & Sons.

[14] Vischer, J.C., Space Meets Status: Designing Workplace Performance. 1 ed. 2005, Oxford: Routledge.

[15] Alfirević, Đ., and Simonović Alfirević, S., Open-plan in Housing Architecture: Origin, Development and Design Approaches for Spatial Integration. Arhitektura i urbanizam, 2016. 43: p. 45–60. https://doi.org/10.5937/a-u0-11551

[16] Gürsel Dino, İ., and Üçoluk, G., Multiobjective Design Optimization of Building Space Layout, Energy, and Daylighting Performance. Journal of Computing in Civil Engineering, 2017. 31(5): p.04017025. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000669

[17] Alfirević, Đ., Simonović Alfirević, S., and Nikolić, S., Impact of internal openness on the sustainability of residential space. Open House International, 2025. 50(5): p. 857–878. https://doi.org/10.1108/OHI-04-2024-0144

[18] Qaradaghi, A.M.A., The effect of rural building types informing the type of traditional courtyard houses in Sulaimaneyah city. Journal of Planner and Development, 2021. 25(2): p. 158–183.

[19] Yuns, M.M., and Qaradaghi, A.M.A., The Impact of Rapid Growth on the Architectural Aspects of Housing Complexes in Sulaymaniyah City. Eurasian Journal of Science and Engineering, 2026. 11(3): p. 339–357. https://doi.org/ 10.23918/eajse.v11i3p22

[20] Al Jarah, S.H., Zhou, B., Abdullah, R.J., Lu, Y., and Yu, W., Urbanization and Urban Sprawl Issues in City Structure: A Case of the Sulaymaniah Iraqi Kurdistan Region. Sustainability, 2019. 11(2): p. 485. https://doi.org/10.3390/su11020485

[21] Ali, L.S., and Qaradaghi, A.M.A., The Effect of Subdivision Regulations on Housing Typologies. Sulaimani Journal for Engineering Sciences, 2023. 10(2): p. 61–77. https://doi.org/10.17656/sjes.10173

[22] CIBSE, Guide F: Energy Efficiency in Buildings. 3 ed. 2012, London: Chartered Institution of Building Services Engineers.

[23] ASHRAE, 2017 ASHRAE Handbook—Fundamentals. SI ed. 2017, Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
[24] Yoshino, H., Hong, T., and Nord, N., IEA EBC Annex 53: Total energy use in buildings—Analysis and evaluation methods. Energy and Buildings,2017.152:p.124–136. https://doi.org/10.1016/j.enbuild.2017.07.038
[25] Elantary, A.R., Energy Consumption Patterns in Residential Buildings: A Comparative Study of Air Conditioning Systems. Yanbu Journal of Engineering and Science, 2025. 22(2): p. 34–47. https://doi.org/10.53370/001c.128314
[26] Istepanian, H.H., Towards Sustainable Energy Efficiency in Iraq. 2020, Amman: Friedrich-Ebert-Stiftung – FES Jordan & Iraq.
[27] Lechner, N., Heating, Cooling, Lighting: Sustainable Design Methods for Architects. 4 ed. 2015, Hoboken, NJ: John Wiley & Sons.
[28] Etheridge, D., and Sandberg, M., Building Ventilation: Theory and Measurement. 1996, Chichester: John Wiley & Sons.
[29] Steemers, K., and Yun, G.Y., Household energy consumption: A study of the role of occupants. Building Research & Information, 2009. 37(5–6):p.625–637. https://doi.org/10.1080/09613210903186661
[30] Albatici, R., and Passerini, F., Bioclimatic design of buildings considering heating requirements in Italian climatic conditions. A simplified approach. Building and Environment, 2011. 46(8): p. 1624–1631. https://doi.org/10.1016/j.buildenv.2011.01.028
[31] Depecker, P., Ménézo, C., Virgone, J., and Lepers, S., Design of buildings shape and energetic consumption. Building and Environment,2001.36(5):p.627–635. https://doi.org/10.1016/S0360-1323(00)00044-5
[32] Ourghi, R., Al-Anzi, A., and Krarti, M., A simplified analysis method to predict the impact of shape on annual energy use for office buildings. Energy Conversion and Management, 2007.48(1):p.300–305. https://doi.org/10.1016/j.enconman.2006.04.011
[33] Goia, F., Search for the optimal window-to-wall ratio in office buildings in different European climates and the implications on total energy saving potential. Solar Energy, 2016. 132: p. 467–492. https://doi.org/10.1016/j.solener.2016.03.031
[34] Tawfeeq, H., and Qaradaghi, A.M.A., Optimising Window-to-Wall Ratio for Enhanced Energy Efficiency and Building Intelligence in Hot Summer Mediterranean Climates. Sustainability, 2024. 16(17): p. 7342. https://doi.org/10.3390/su16177342
[35] Ghisi, E., and Tinker, J.A., An Ideal Window Area concept for energy efficient integration of daylight and artificial light in buildings. Building and Environment, 2005. 40(1): p. 51–61. https://doi.org/10.1016/j.buildenv.2004.04.004
[36] Cook, M.J., Lomas, K.J., and Eppel, H., How do different low energy cooling strategies affect indoor comfort conditions in an office building?. Building and Environment, 2005. 40(2): p. 196–206. https://doi.org/10.1016/j.buildenv.2004.08.008
[37] Szokolay, S.V., Introduction to Architectural Science: The Basis of Sustainable Design. 3 ed. 2014, Abingdon, Oxon: Routledge.
[38] Aldawoud, A., The influence of the atrium geometry on the building energy performance. Energy and Buildings, 2013. 57: p. 1–5. https://doi.org/10.1016/j.enbuild.2012.10.038
[39] Muhaisen, A.S., Shading simulation of the courtyard form in different climatic regions. Building and Environment, 2006. 41(12): p. 1731–1741. https://doi.org/10.1016/j.buildenv.2005.07.016
[40] DeKay, M., and Brown, G.Z., Sun, Wind, and Light: Architectural Design Strategies. 3 ed. 2014, Hoboken, NJ: Wiley.
[41] Latha, H., Patil, S., and Kini, P.G., Influence of architectural space layout and building perimeter on the energy performance of buildings: A systematic literature review. International Journal of Energy and Environmental Engineering, 2023. 14(3): p. 431–474. https://doi.org/ 10.1007/s40095-022-00522-4
[42] U.S. Department of Energy, EnergyPlus™ Version 23.1.0 Documentation: Input Output Reference. 2023, U.S. Department of Energy.

تأثير تخطيط الفضاء المعماري على أداء الطاقة في المباني: الطلب على التدفئة والتبريد في المنازل النموذجية ضمن المشاريع السكنية في مدينة السليمانية

المستخلص

تُعدّ كيفية توزيع الفراغات المعمارية معلمة تصميمية مهمة تؤثر في الطلب على التدفئة والتبريد، إلا أنها حظيت باهتمام أقل مقارنةً بمتغيرات التصميم الأخرى، ولا سيما في مناخات البحر الأبيض المتوسط ذات الصيف الحار. تبحث هذه الدراسة في كيفية تأثير تحويل المخططات المفتوحة إلى مخططات خلوية على الطلب على التدفئة والتبريد في المباني السكنية في مدينة السليمانية، العراق. تم نمذجة ثلاثة منازل مختارة لعائلات منفردة باستخدام محرك المحاكاة DesignBuilder/EnergyPlus. وتم تطوير سيناريوهين لفصل تأثيرات التقسيم الفراغي. اختبر السيناريو A التقسيم الفراغي مع الإبقاء على افتراضات النشاط والتشغيل الأساسية، في حين جمع السيناريو B بين التقسيم الفراغي والتقسيم الحراري الوظيفي الواقعي من خلال تخصيص أنماط إشغال خاصة بكل غرفة. وتمت محاكاة أحمال التدفئة والتبريد السنوية في ظل ظروف نظام HVAC المثالي، تلاها تحليل حساسية لمعدل تهوية مفروض. تشير النتائج إلى أن التقسيم الفراغي المضبوط أدى إلى تغيّرات صغيرة وغير متسقة في الطلب الحراري ضمن الافتراضات التي تم اختبارها. وفي السيناريو B، أدت المخططات الخلوية ذات التشغيل الوظيفي الخاص بكل فراغ إلى خفض الطلب السنوي على التدفئة والتبريد على مستوى المبنى ككل بنسبة تراوحت بين ٢.٥٠٪ و٤.٤٨٪، على الرغم من تطبيق التقسيم الفراغي على الطابق الأرضي فقط. وانخفض الطلب على التدفئة بصورة متسقة في الحالات الثلاث، بينما تغير الطلب على التبريد بشكل طفيف فقط، إذ انخفض في حالتين وارتفع بشكل طفيف في حالة واحدة. كما أدى شرط التهوية المفروض إلى خفض إضافي في الطلب على التبريد في كلا التخطيطين دون تغيير ترتيبهما النسبي من حيث الطلب الحراري. وبشكل عام، تشير النتائج إلى أن التقسيم الفراغي وحده أحدث تأثيرات حرارية محدودة، في حين أدى الجمع بين التقسيم والتشغيل الوظيفي الخاص بكل فراغ إلى تغيّرات أكبر في الطلب الحراري.

الكلمات المفتاحية:

تخطيط الفضاء المعماري؛ أداء الطاقة في المباني؛ الطلب على التدفئة؛ الطلب على التبريد؛ التخطيط المفتوح؛ التخطيط الخلوي؛ المباني السكنية؛ DesignBuilder؛ EnergyPlus.

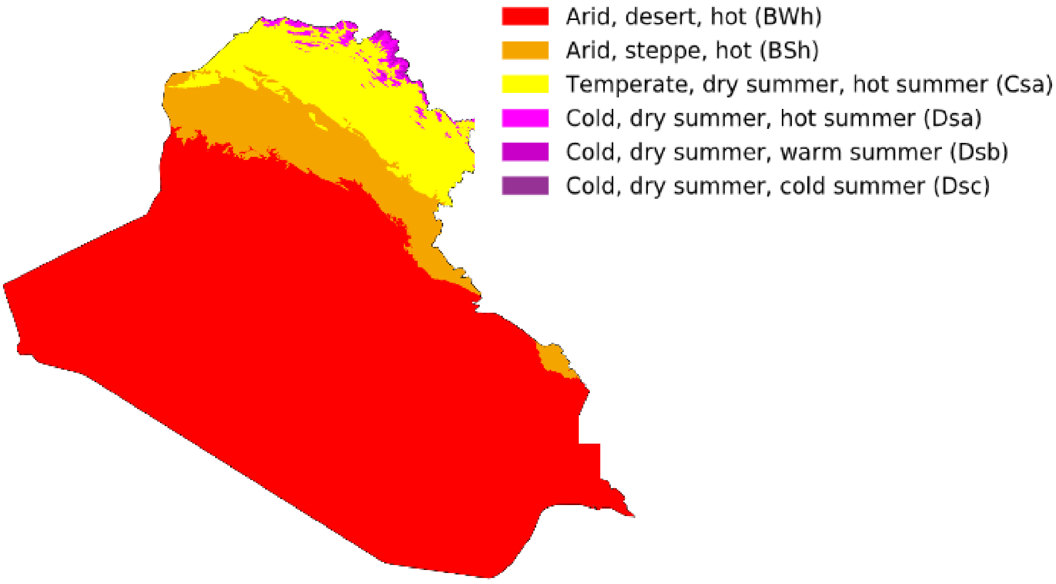


Figure 1: Köppen-Geiger climate classification map for Iraq (1991-2020). [10]

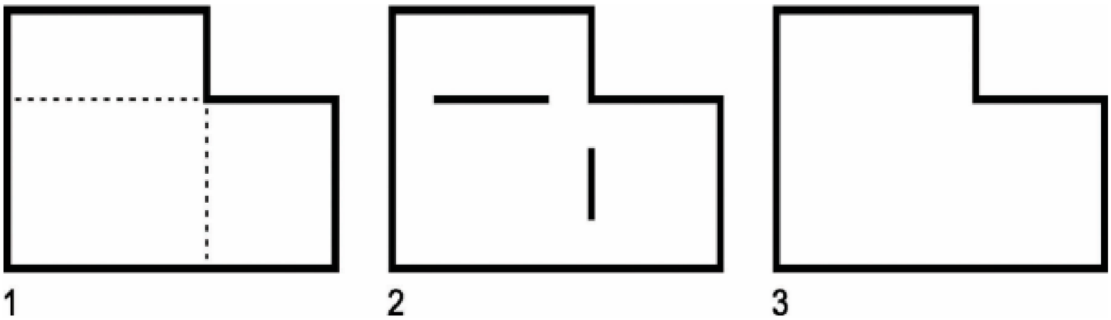


Figure 2: Basic approaches to room integration: 1) flexible space, 2) fluid space and 3) all-in-one space [15].

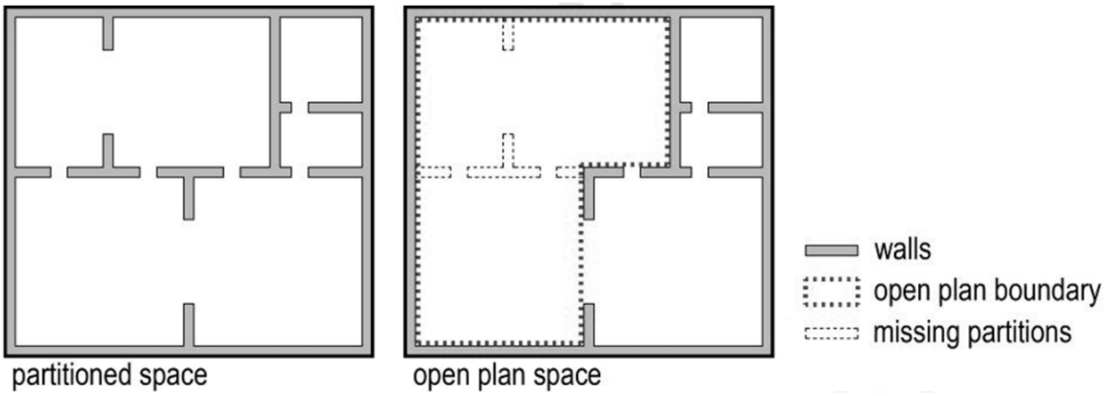


Figure 3: Difference between partitioned space and open plan space [17].

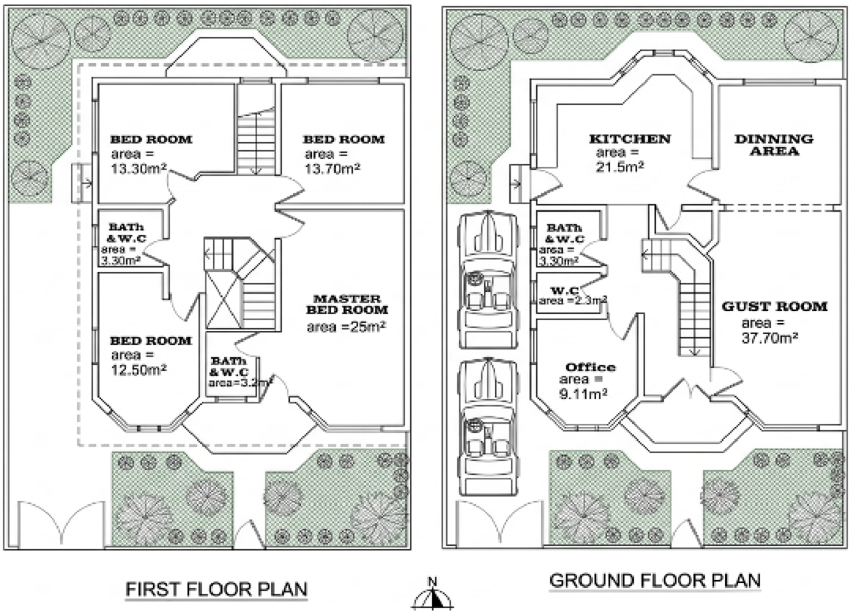


Figure 4: Typical plans of German Village houses, 2007 (Researcher).

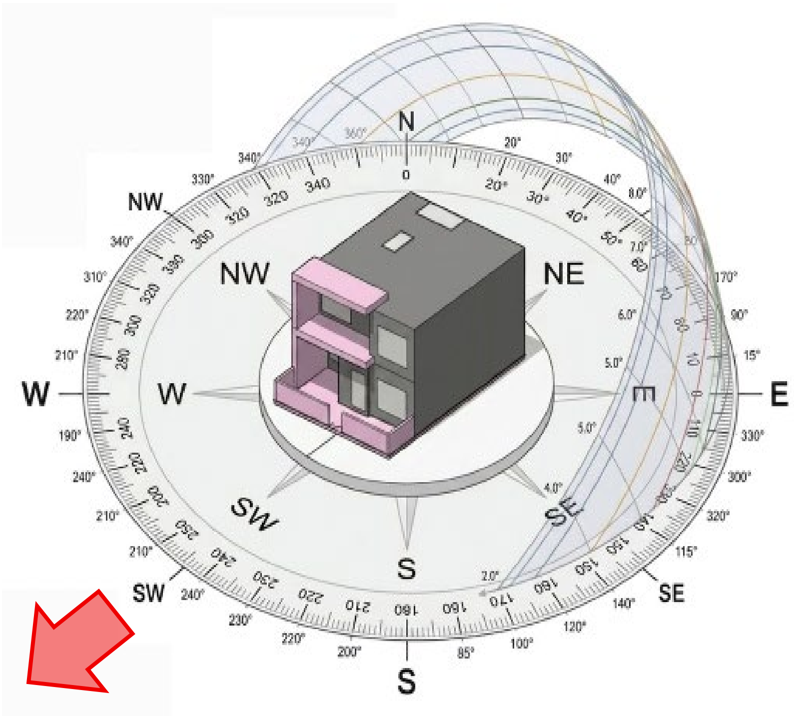


Figure 5: Orientation of South-west was chosen for the simulation of the three selected cases (Researcher).

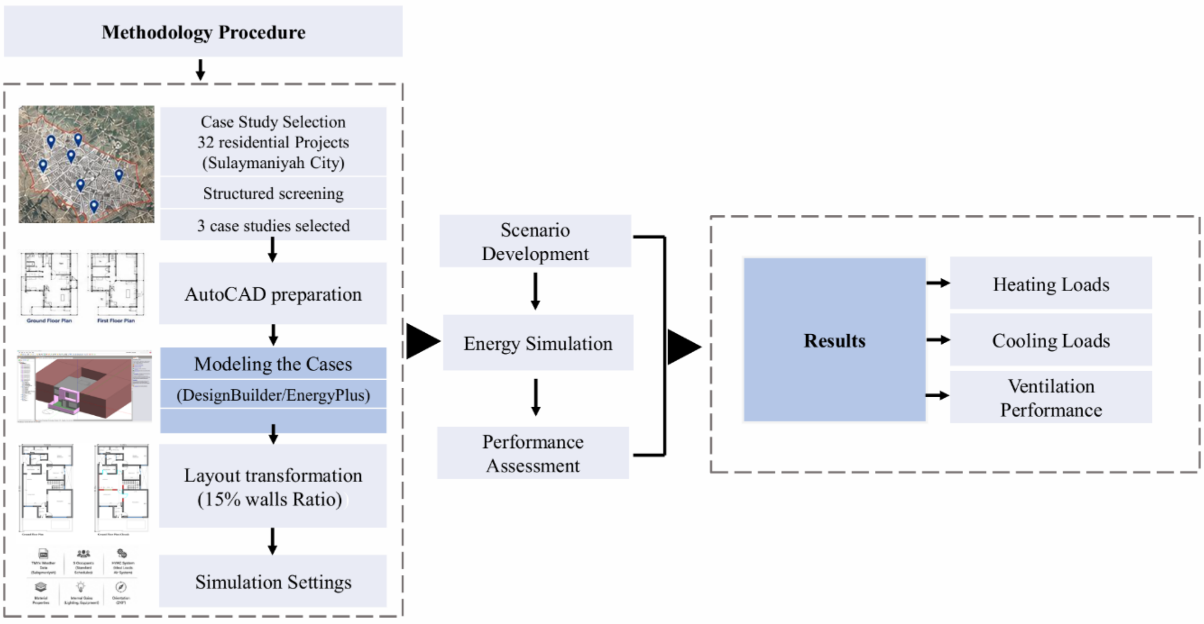


Figure 6: Research methodology procedure (Researcher).

Table 1 Evaluation of the Selected Case Studies Against the Eligibility Criteria

Project No.	**Location** (Sulaymaniyah)	**Function** (Single-family House)	**Typology** (Row House)	**Plot Area** (150-200)	**Floors** (2 floors)	**Layout** (Open Plan)	**Period** (2015-2025)	**Period** (Medium Income)
1- Aro City	✓	✓	✓	✓	✓	✓	✓	✓
2- Deru City	✓	✓	✓	✓	✓	✓	✓	✓
3- Qaiwan City	✓	✓	✓	✓	✓	✓	✓	✓
4- Green City	✓	✓	✓	✓	✗	✓	✓	✗
5- Lubnan City	✓	✓	✓	✓	✓	✓	✓	✗
6- Brwa City	✓	✓	✓	✓	✓	✗	✓	✗
7- Diya City	✓	✓	✓	✓	✗	✗	✓	✗

Note: *A total of 33 housing projects were evaluated using the same eligibility criteria. For brevity, only seven projects are presented here, including the three projects that satisfied all criteria and four examples of excluded projects.*

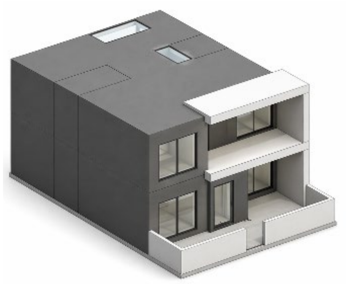
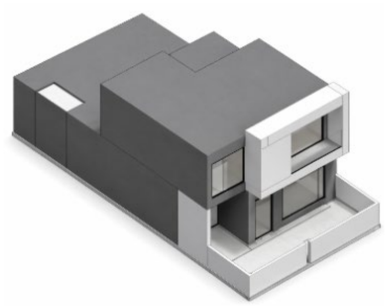
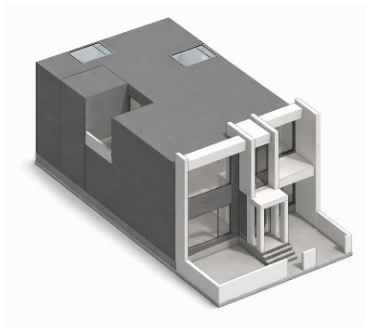
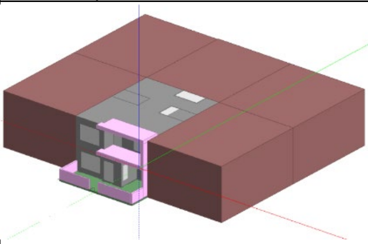
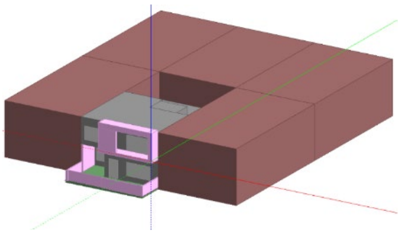
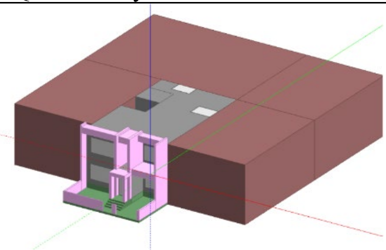
Case Study	Plot Area (m²)	Built Area (m²)	Window-to-Wall Ratio WWR (%)	Surface-to-Volume Ratio, S/V (m^{-1})	Skylight Area (m²)
Aro City	150	180.58	24.91	0.61	6.66
Deru City	200	210.07	23.61	0.71	11.21
Qaiwan City	200	243.77	21.06	0.63	7.18
 Aro City 3D view		 Deru City 3D View		 Qaiwan City 3D view	
 DesignBuilder Modeling		 DesignBuilder Modeling		 DesignBuilder Modeling	
 Ground and First Floor Plan		 Ground and First Floor Plan		 Ground and First Floor Plan	

Table 2 Characteristics of the Three Selected Case Studies.

Table 3 Number of Houses within Each Project and Orientations They Face

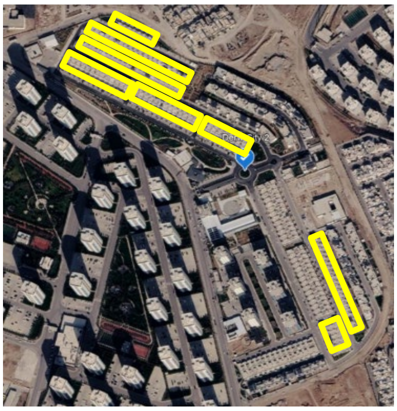
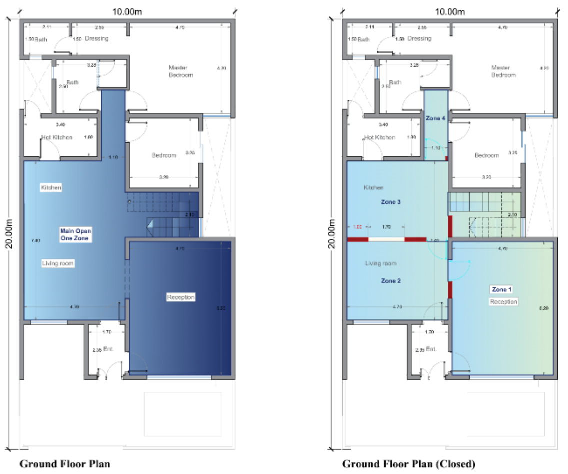
<table>
<tr><th>NO.</th><th>Selected Residential Projects</th><th>Number of Houses in the Project</th><th>South-west</th><th>North-East</th><th>South-East</th><th>North-West</th><th>East</th><th>West</th></tr>
<tr><td>1</td><td>Aro City</td><td>72</td><td>36</td><td>36</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>Deru City 2</td><td>130</td><td>79</td><td>51</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>3</td><td>Qaiwan City</td><td>109</td><td>30</td><td>42</td><td>9</td><td>10</td><td>9</td><td>9</td></tr>
<tr><td></td><td>Total Houses</td><td>311</td><td>145</td><td>129</td><td>9</td><td>10</td><td>9</td><td>9</td></tr>
<tr><td colspan="2">Case Study</td><td colspan="3">Aerial photo of the residential project</td><td colspan="4">Orientation Analysis</td></tr>
<tr><td colspan="2">Aro City</td><td colspan="3"></td><td colspan="4"></td></tr>
<tr><td colspan="2">Deru City</td><td colspan="3"></td><td colspan="4"></td></tr>
<tr><td colspan="2">Qaiwan City</td><td colspan="3"></td><td colspan="4"></td></tr>
</table>

Table 4 Internal Partition Density Increase for Case Studies.

Case Study	Original Internal Wall Area (m²)	Added Wall Area (m²)	Added Wall Ratio (%)	Limited ratio of added walls (15%)
Aro City	448.24	34.688	7.74%	**15%**
Deru City	505.85	51.068	10.10%	**15%**
Qaiwan City	486.43	41.60	8.55%	**15%**

Original open ground floor plan alongside the modified cellular ground floor plan with Zones Specifications

Aro City



Deru City

Qaiwan City

Table 5 Simulation scenario definitions, controlled variables, and quantitative verification

Parameter	Open-plan baseline	Scenario A: Controlled Spatial Subdivision	Scenario B: Spatial Subdivision with Function-Specific Operation
Spatial configuration	Original open-plan configuration	Internal partitions added	Same cellular configuration as Scenario A
Thermal zoning	Original zoning	New zones according to subdivision	Same as Scenario A
Conditioned spaces	All modeled zones conditioned, **except open zones.**	Same	Same
Activity assignment	Domestic Lounge profile	Same base activity assumptions retained	Function-specific residential profiles
Occupancy density / schedule	0.050 person/m²; Dwell_DomLounge_Occ	Same	Function-specific profiles and schedules
Heating setpoint / schedule	21/16°C; Dwell_DomLounge_Heat	Same	Function-specific profiles and schedules
Cooling setpoint / schedule	24/26°C; Dwell_DomLounge_Cool	Same	Function-specific profiles and schedules
Equipment input / schedule	5.00 W/m²; Dwell_DomLounge_Equip	Same	Function-specific profiles and schedules
Lighting input / schedule	2.50 W/m² per 100 lux; target 150 lux; Dwell_DomLounge_Light	Same	Function-specific profiles and schedules
Infiltration	0.70 ACH, 24/7	Same	Same
Mechanical ventilation	Off	Off	Off
Natural ventilation in baseline load simulations	Off	Off	Off
HVAC model	Ideal Loads Air System	Same	Same
Orientation	210° SW	Same	Same
Weather data	Sulaymaniyah TMYx	Same	Same
External envelope	Baseline construction	Same	Same
Internal partitions	Existing configuration	100-mm lightweight concrete block	Same as Scenario A
DesignBuilder net conditioned zone floor area — Aro	180.58 m²	179.51 m²	179.51 m²
DesignBuilder net conditioned zone floor area — Deru	210.07 m²	208.18 m²	208.18 m²
DesignBuilder Net-conditioned zone floor area — Qaiwan	243.77 m²	241.53 m²	241.53 m²
Conditioned zones Ground Floor — Aro City	5 Zones	8 zones	8 zones
Conditioned zones Ground Floor — Deru City	7 Zones	10 zones	10 zones
Conditioned zones Ground Floor — Qaiwan City	6 Zones	9 zones	9 zones
Annual gains — Aro City (People / Lighting / Equipment, kWh)	988.24 / 1258.77 / 2240.65	847.88 / 1248.59 / 2114.29	857.90 / 1385.39 / 2703.90
Annual gains — Deru City	775.08 / 1560.95 / 2262.75	770.09 / 1542.83 / 2236.69	770.69 / 1768.75 / 3230.30
Annual gains — Qaiwan City	1300.04 / 4924.63 / 3199.17	1139.00 / 4875.11 / 3042.08	1132.79 / 5044.60 / 3622.14
Conditioned volume — Aro City (m³):	606.62 m³	603.22 m³	603.22 m³
Conditioned volume — Deru City (m³):	671.43	665.37	665.37
Conditioned volume — Qaiwan City (m³):	793.47 m³	786.30 m³	786.30 m³

Note: The cellular zoning configuration shown for each case applies to both Scenario A and Scenario B. Scenario B retains the same cellular geometry and thermal-zone topology as Scenario A and differs only through the assignment of function-specific operational profiles.

Table 6 Principal simulation inputs and modelling assumptions

Category	Input / assumption
Software	DesignBuilder with EnergyPlus 9.4.0
Simulation period	Annual simulation, 8760 h
Weather file	Sulaymaniyah, WMO 406230
External wall	200-mm hollow block + 50-mm EPS; U ≈ 0.58 W/m²·K
Roof	19-mm asphalt + 13-mm fibreboard + reinforced-concrete slab (~150 mm) + internal plaster, U = 2.30 W/m²·K.
Ground floor	Uninsulated 300-mm cast-concrete slab + Tile, U = 2.339 W/m²·K.
Glazing	Double glazing, U = 2.67 W/m²·K, g = 0.59
Internal partitions	100-mm concrete block
Infiltration	DesignBuilder-assigned zone rates, approximately 0.70–0.72 ACH
HVAC representation	Ideal Loads Air System; each conditioned zone individually conditioned
Heating/cooling control	All conditioned zones: heating setpoint/setback = 21/16°C; cooling setpoint/setback = 24/26°C
Occupancy	Occupancy — Nominal five-person household; zone-level occupancy represented using scenario-specific DesignBuilder occupancy densities and schedules.
Prescribed ventilation-rate sensitivity	2 ACH when occupied and outdoor temperature 18–32°C
Scenario control	Envelope, weather, orientation and simulation settings held constant between compared layouts
Note: Other numerical solutions, heat-balance, solar and shadow-calculation settings were retained consistently across all comparative simulations; individual values are not reported where they could not be independently verified from the available simulation records.	

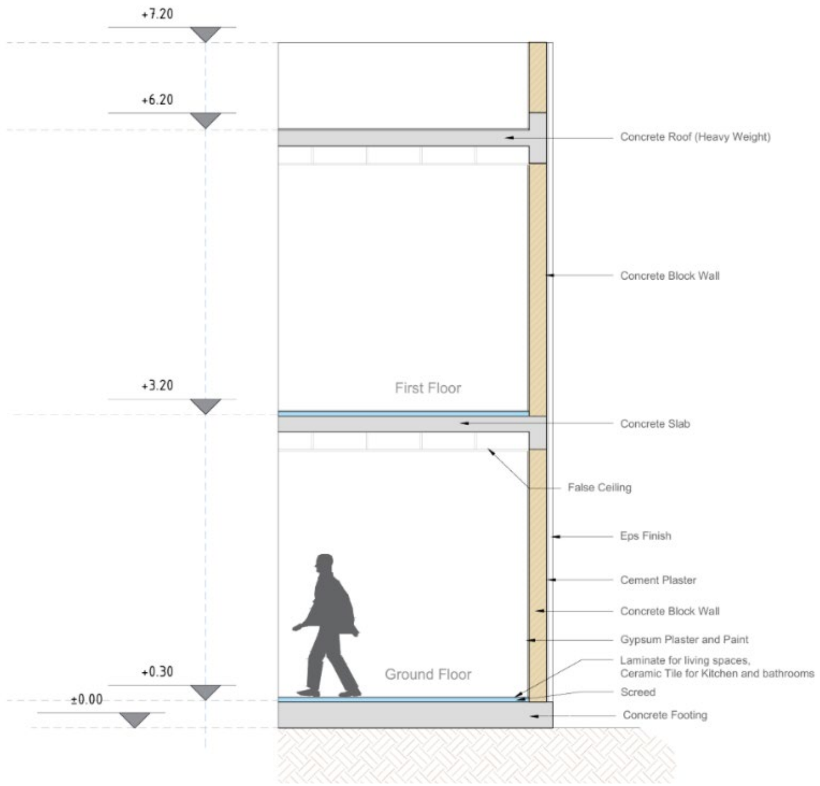


Figure 7: A typical section of a selected sample's footing, wall, and ceiling (Researcher).

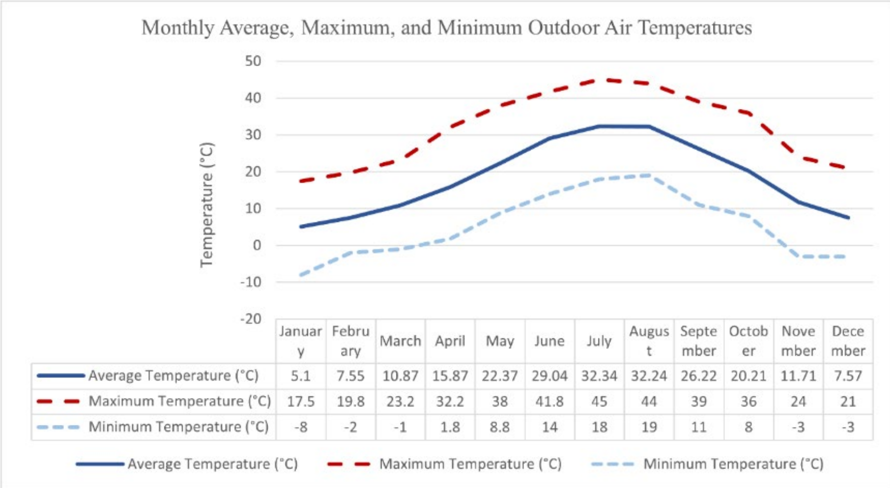


Figure 8: Monthly Average, Maximum, and Minimum Outdoor Air Temperatures for As Sulaymaniyah city. (TMYx 2011–2025), (Researcher).

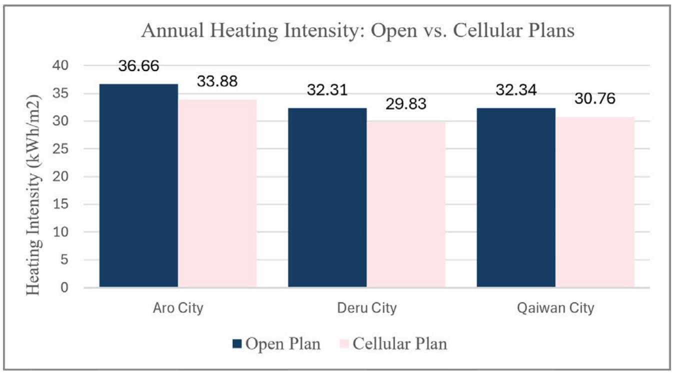


Figure 9: Annual heating intensity of open- and cellular-plan configurations (whole building), (Researcher).

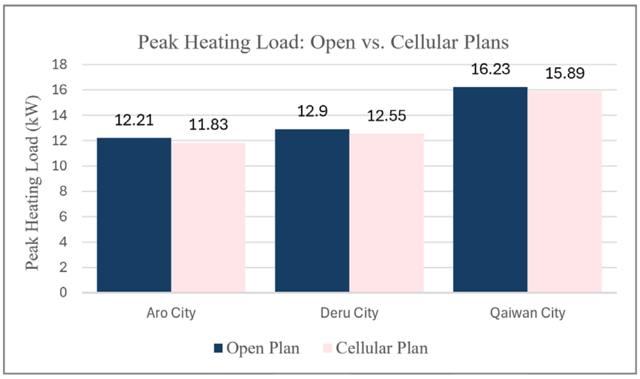


Figure 10: Whole-building peak heating loads of open- and cellular-plan configurations, (Researcher).

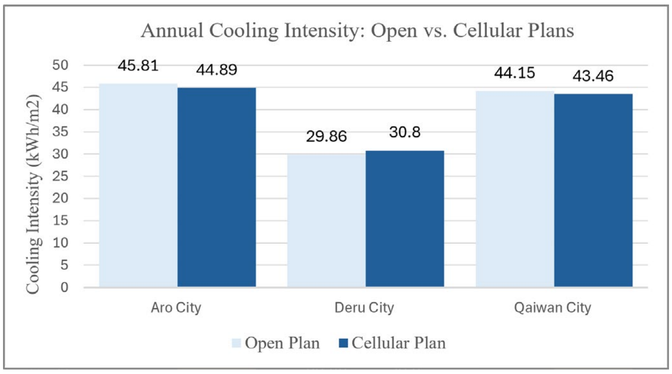


Figure 11: Annual Cooling intensity of open- and cellular-plan configurations (whole building), (Researcher)

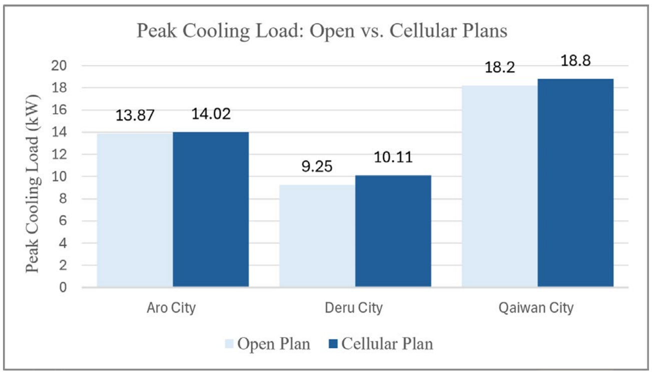


Figure 12: Whole-building peak cooling loads of open- and cellular-plan configurations, (Researcher).

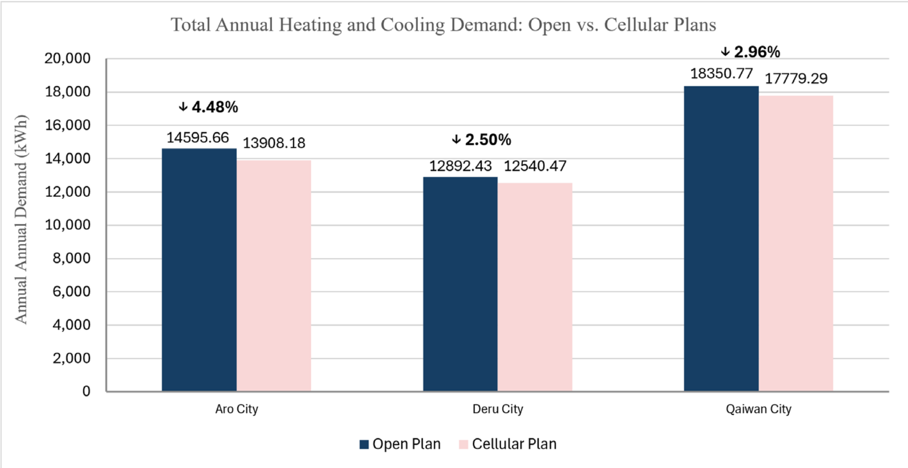


Figure 13: Total annual heating and cooling demand of open- and cellular-plan configurations across the three case studies, (Researcher).

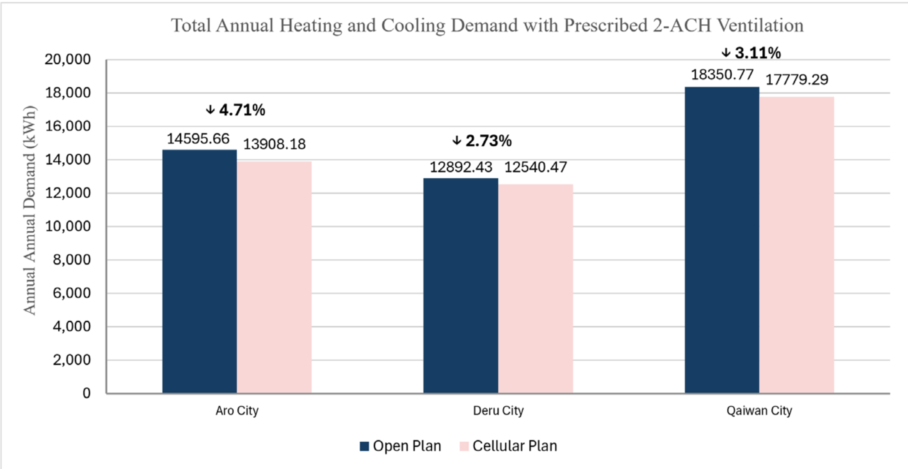


Figure 14: Whole-building total annual heating and cooling demand of open- and cellular-plan configurations under the prescribed 2-ACH ventilation conditions, (Researcher).

Note: In the following Tables, Percentage reduction was calculated relative to the corresponding open-plan value as: Percentage reduction (%) = [(Open-plan value − Cellular-plan value) / Open-plan value] × 100. Unless otherwise stated, signed differences were calculated as Open plan − Cellular plan.

Table 7 Combined annual heating and cooling thermal demand and Intensity Comparison Between Open-Plan and Cellular-Plan Configurations Under Scenario A (Spatial Enclosure Without Functional Reallocation) — three Case Studies, (Whole Building).

Case Study	Original Open Plan Total Loads Intensity (kWh/m²)	Scenario A cellular Plan Total Intensity (kWh/m²)	Scenario A Difference (kWh/m²)	**Scenario A Change (%)**	Scenario B Difference (kWh/m²)	**Scenario B Change (%)**
Aro City	82.47	81.15	1.32	**1.60%**	3.70	**4.48%**
Deru City	62.17	62.21	-0.04	**-0.06%**	1.54	**2.50%**
Qaiwan City	76.49	75.80	0.69	**0.90%**	2.27	**2.96%**

Table 8 Annual Heating Load (kWh) and Heating Intensity (kWh/m²) of the Original open plan layout of the three case studies, (Whole Building).

Case Study	Area (m²)	Window-to-Wall Ratio, WWR (%)	Surface-to-Volume Ratio, S/V (m⁻¹)	Skylight Area (m²)	Annual Heating Load (kWh)	Heating Intensity (kWh/m²)
Aro City	180.58	24.91	0.61	6.66	6619.51	36.66
Deru City	210.07	23.61	0.71	11.21	6788.38	32.31
Qaiwan City	243.77	21.06	0.63	7.18	7884.22	32.34

Table 9 Annual Heating loads and intensity of cellular plans in comparison with heating loads intensity of open plans (Whole Building).

Case Study	Area (m²)	Open Plan Annual Heating Load (kWh)	Open Plan Heating Intensity (kWh/m²)	Cellular Plan Annual Heating Load (kWh)	Cellular Plan Heating Intensity (kWh/m²)	Absolute Difference (kWh/m²) Open -cellular	Reduction (%)
Aro City	180.58	6619.51	36.66	6118.14	33.88	2.78	7.57%
Deru City	210.07	6788.38	32.31	6266.56	29.83	2.48	7.69%
Qaiwan City	243.77	7884.22	32.34	7499.71	30.76	1.58	4.88%

Table 10 Peak Heating loads of both open and cellular plans (kW), (Whole Building).

Plan Configurations	Open Plan	Cellular Plan	Difference Open – cellular	Reduction (%)
Case Studies	Whole-Building Peak Heating Load (kW)	Whole-Building Peak Heating Load (kW)		
Aro City	12.210	11.830	0.380	3.11%
Deru City	12.900	12.550	0.350	2.71%
Qaiwan City	16.230	15.890	0.340	2.09%

Table 11 Annual Cooling Load (kWh) and Cooling Intensity (kWh/m²) of the Original open plan layout of the three case studies, (Whole Building).

Case Study	Area (m²)	Window-to-Wall Ratio, WWR (%)	Surface-to-Volume Ratio, S/V (m⁻¹)	Skylight Area (m²)	Annual Cooling Load (kWh)	Cooling Intensity (kWh/m²)
Aro City	180.58	24.91	0.61	6.66	8273.24	45.81
Deru City	210.07	23.61	0.71	11.21	6273.47	29.86
Qaiwan City	243.77	21.06	0.63	7.18	10763.70	44.15

Table 12 Annual Cooling loads and intensity of original open plans in comparison with Cooling loads intensity of cellular plans, (Whole Building).

Case Study	Area (m²)	Open Plan Annual Cooling Load (kWh)	Open Plan Cooling Intensity (kWh/m²)	Cellular plan Annual Cooling Load (kWh)	Cellular Plan Cooling Intensity (kWh/m²)	Absolute Difference (kWh/m²) Open – cellular	% Reduction
Aro City	180.58	8273.24	45.81	8106.77	44.89	0.92	2.01%
Deru City	210.07	6273.47	29.86	6470.27	30.80	-0.94	-3.14%
Qaiwan City	243.77	10763.70	44.15	10594.83	43.46	0.69	1.57%

Table 13 Peak cooling loads of both open and cellular plans (kW), (Whole Building).

Plan Configurations	**Open Plan**	**Cellular Plan**	**Difference Open - Cellular**	**% Reduction**
Case Studies	**Whole-Building Peak Cooling Load (kW)**	**Whole-Building Peak Cooling Load (kW)**		
Aro City	13.87	14.02	-0.15	-1.08%
Deru City	9.25	10.11	-0.86	-9.30%
Qaiwan City	18.20	18.80	-0.60	-3.30%

Table 14 Total Annual Thermal of Open-Plan and Cellular Plan Configurations Across All Case Studies, (Whole Building).

		Open Plan			Cellular Plan			Absolute Difference (kWh)	% Reduction
Case Study	**Area (m²)**	**Annual Heating Load (kWh)**	**Annual Cooling Load (kWh)**	**Total Annual Loads (kWh)**	**Annual Heating Load (kWh)**	**Annual Cooling Load (kWh)**	**Total Annual Loads (kWh)**	**Open Plan – Cellular plan annual Loads (kWh)**	**Percentage Reduction (%)**
Aro City	180.58	6619.51	8273.24	14892.75	6118.14	8106.77	14224.91	667.84	**4.48%**
Deru City	210.07	6788.38	6273.47	13061.85	6266.56	6470.27	12736.83	325.02	**2.50%**
Qaiwan City	243.77	7884.22	10763.70	18647.92	7499.71	10594.83	18094.54	553.38	**2.96%**

Note: Thermal loads were calculated under ideal HVAC ideal load conditions without mechanical ventilation or the prescribed 2-ACH ventilation condition. Also, Change was calculated as Open-plan − Cellular-plan; therefore, positive values indicate a reduction under the cellular configuration, while negative values indicate an increase (deterioration).

Table 15 Monthly Heating and Cooling Thermal Demand (kWh) in Open Plan Configuration (Whole Building)

Case	**Metric**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Aro City	**Total Cooling (kWh)**	0.00	0.00	-2.55	- 114.57	- 565.87	- 1796.77	- 2491.99	- 2252.03	-907.63	- 141.83	0.00	0.00
	Zone Heating (kWh)	2078.70	1284.87	660.90	130.37	0.00	0.00	0.00	0.00	0.00	34.78	740.61	1689.27
Deru City	**Total Cooling (kWh)**	0.00	0.00	-0.32	-50.97	- 312.61	- 1357.92	- 1972.60	- 1786.91	-676.91	- 115.22	0.00	0.00
	Zone Heating (kWh)	2050.65	1327.89	731.02	171.10	0.14	0.00	0.00	0.00	0.00	44.64	781.40	1681.55
Qaiwan City	**Total Cooling (kWh)**	0.00	0.00	-0.98	- 140.96	- 758.41	- 2305.67	- 3180.21	- 2902.67	- 1237.28	- 237.53	0.00	0.00
	Zone Heating (kWh)	2529.62	1541.77	761.24	143.67	0.00	0.00	0.00	0.00	0.00	34.51	840.52	2032.90

Table 16 Monthly Heating and Cooling Thermal Demand (kWh) in Cellular Plan Configuration (Whole Building)

Case	**Metric**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Aro City	**Total Cooling (kWh)**	0.00	0.00	-2.57	- 112.26	- 545.63	- 1,760.7	- 2,459.03	- 2,215.5	-876.19	- 134.80	0.00	0.00
	Zone Heating (kWh)	1,960.21	1,194.37	590.99	109.72	0.00	0.00	0.00	0.00	0.00	25.57	656.91	1,580.36
Deru City	**Total Cooling (kWh)**	0.00	0.00	-0.33	-56.27	- 337.45	- 1396.30	- 2015.97	- 1826.85	-707.48	- 129.63	0.00	0.00
	Zone Heating (kWh)	1930.91	1231.35	657.19	146.47	0.17	0.00	0.00	0.00	0.00	36.39	700.48	1563.60
Qaiwan City	**Total Cooling (kWh)**	0.00	0.00	-0.99	- 140.02	- 739.09	- 2268.83	- 3146.33	- 2864.97	-1204.36	- 230.24	0.00	0.00
	Zone Heating (kWh)	2425.60	1469.32	713.67	132.36	0.00	0.00	0.00	0.00	0.00	28.78	784.13	1946.01

Note: Cooling thermal-energy values are reported as negative because they represent heat removed from the thermal zone, following the DesignBuilder/EnergyPlus sign convention. Heating values are positive because they represent heat added to the zone. A value of 0.00 indicates no heating or cooling demand during that month.

Table 17 Comparative Analysis of Annual Cooling and Heating Energy Loads with prescribed 2-ACH ventilation condition— All Case Studies

Case Study	Cooling Loads								Heating Loads					
	Baseline Cooling (kWh)		With Prescribed Ventilation – Cooling (kWh)		Cooling Savings (kWh)		Cooling Savings (%)		Baseline Heating (kWh)		With Prescribed Ventilation – Heating (kWh)		Heating Variance (kWh)	
	Open	Cellular	Open	Cellular	Open	Cellular	Open	Cellular	Open	Cellular	Open	Cellular	Open	Cellular
Aro City	8,273.24	8,106.77	7,968.71	7,785.96	304.53	320.81	3.68%	3.96%	6,619.51	6,118.14	6,626.95	6,122.22	7.44	4.08
Deru City	6,273.47	6,470.27	6,103.80	6,273.84	169.67	196.43	2.70%	3.04%	6,788.38	6,266.56	6,788.63	6,266.63	0.25	0.07
Qaiwan City	10,763.70	10,594.83	10,466.21	10,279.42	297.49	315.41	2.76%	2.98%	7,884.22	7,499.71	7,884.56	7,499.87	0.34	0.16

Note: Ventilation cooling reduction (%) = [(Cooling demand without prescribed ventilation − Cooling demand with prescribed ventilation) / Cooling demand without prescribed ventilation] × 100.

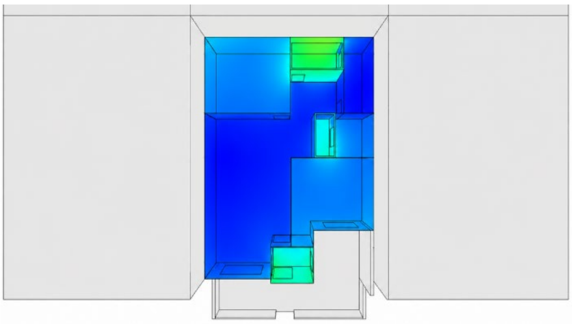
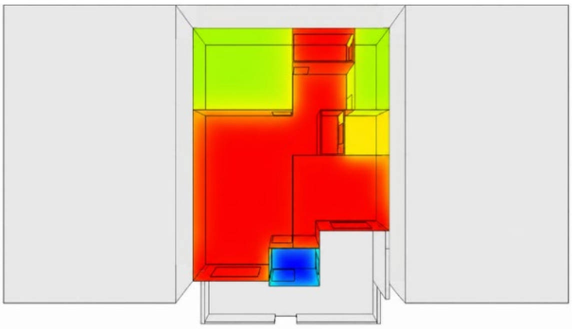
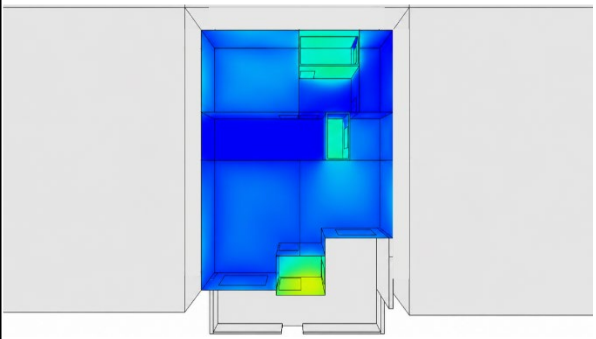
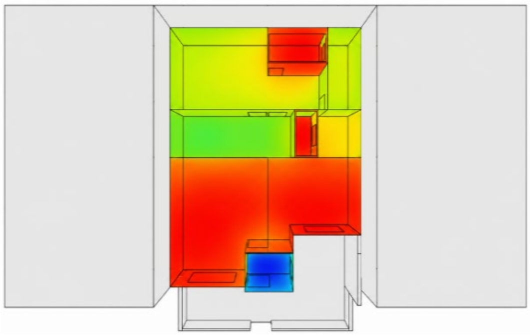
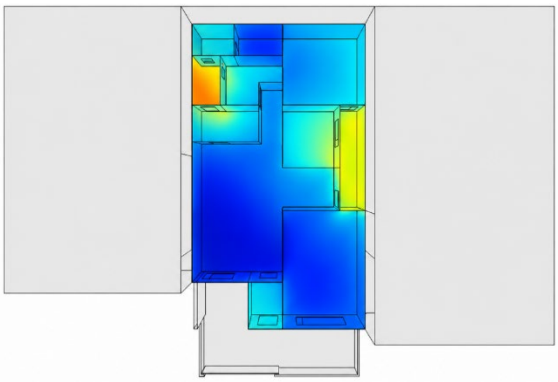
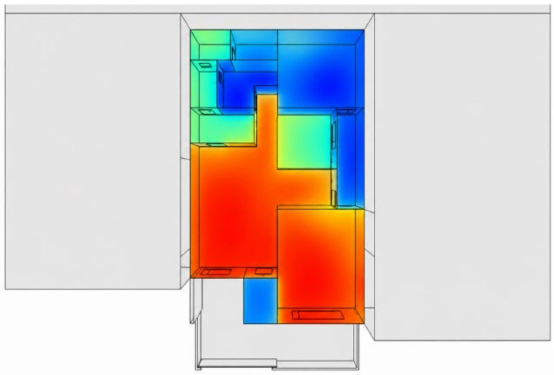
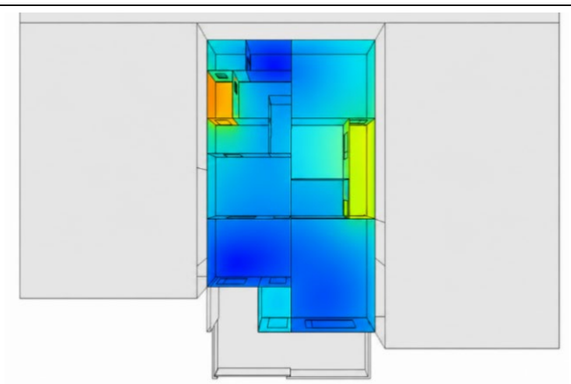
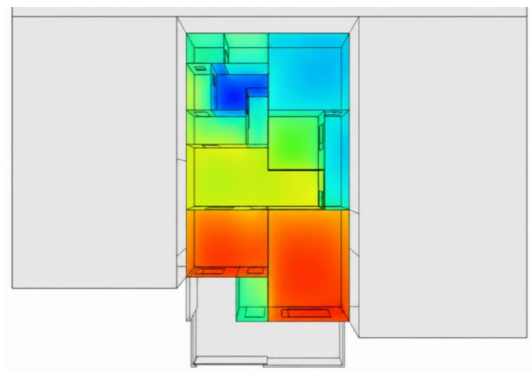
Table 18 Total **Annual** Thermal of Open-Plan and Cellular-Plan Configurations with Prescribed 2-ACH Ventilation Condition Across All Case Studies, (Whole Building).

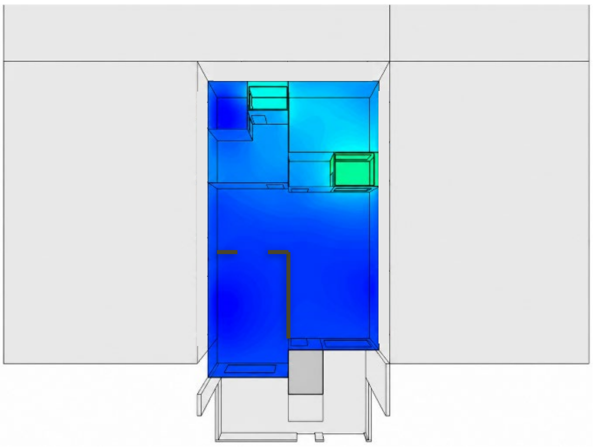
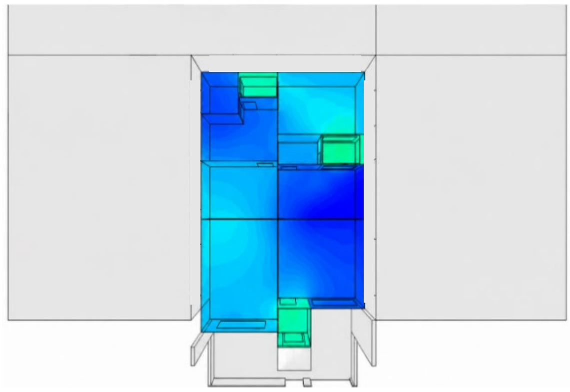
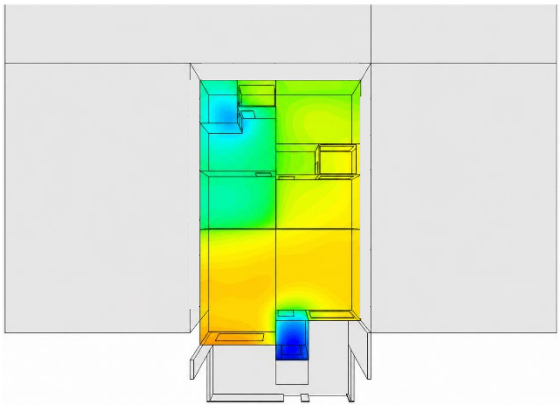
		Open Plan			Cellular Plan			Absolute Difference (kWh)	% Reduction
Case Study	Area (m²)	Annual Heating Load (kWh)	Annual Cooling Load (kWh)	Total Annual Loads (kWh)	Annual Heating Load (kWh)	Annual Cooling Load (kWh)	Total Annual Loads (kWh)	Open Plan – Cellular plan annual Loads (kWh)	Percentage Reduction (%)
Aro City	180.58	6,626.95	7,968.71	14,595.66	6,122.22	7,785.96	13,908.18	687.48	**4.71%**
Deru City	210.07	6,788.63	6,103.80	12,892.43	6,266.63	6,273.84	12,540.47	351.96	**2.73%**
Qaiwan City	243.77	7,884.56	10,466.21	18,350.77	7,499.87	10,279.42	17,779.29	571.48	**3.11%**

Note: Thermal loads were calculated under ideal load conditions with the Prescribed 2-ACH Ventilation Condition.

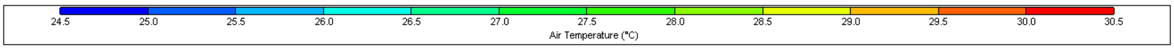
Table 19 Heating and Cooling Thermostat-Setpoint Sensitivity Analysis for Open-Plan and Scenario B Configurations

Cooling sensitivity					
Case study	**Setpoint variation**	**Open plan (kWh/year)**	**Scenario B (kWh/year)**	**Difference (kWh/year)**	**Savings (%)**
Aro City	Original −1°C	9142.82	8976.90	165.92	**1.81%**
Aro City	**Original settings**	**8273.24**	**8106.77**	166.47	**2.01%**
Aro City	Original +1°C	7514.52	7369.22	145.30	**1.93%**
Deru City	Original −1°C	7312.65	7570.17	–257.52	**–3.52%**
Deru City	**Original settings**	6273.47	6470.27	–196.80	**–3.14%**
Deru City	Original +1°C	5408.86	5541.80	–132.94	**–2.46%**
Qaiwan City	Original −1°C	11837.63	11681.48	156.15	**1.32%**
Qaiwan City	**Original settings**	**10763.70**	**10594.83**	168.87	**1.57%**
Qaiwan City	Original +1°C	9827.77	9669.85	157.92	**1.61%**
Heating sensitivity					
Case study	**Setpoint variation**	**Open plan (kWh/year)**	**Scenario B (kWh/year)**	**Difference (kWh/year)**	**Savings (%)**
Aro City	Original −1°C	5698.76	5305.22	393.54	**6.91%**
Aro City	**Original settings**	6619.51	6118.14	501.37	**7.57%**
Aro City	Original +1°C	7732.06	7119.68	612.38	**7.92%**
Deru City	Original −1°C	5466.95	5019.13	447.82	**8.19%**
Deru City	**Original settings**	6788.38	6266.56	521.82	**7.69%**
Deru City	Original +1°C	8269.03	7688.11	580.92	**7.03%**
Qaiwan City	Original −1°C	6721.69	6428.63	293.06	**4.36%**
Qaiwan City	**Original settings**	7884.22	7499.71	384.51	**4.88%**
Qaiwan City	Original +1°C	9312.97	8824.97	488.00	**5.24%**

 Open Plan	
 Cellular Plan	
Aro City: Cooling Temperature Distribution Map between Open and Cellular Plans	**Aro City:** Heating Temperature Distribution Map between Open and cellular Plans
	
	
Deru City: Cooling Temperature Distribution Map between Open and Cellular Plans	**Deru City:** Heating Temperature Distribution Map between Open and Cellular Plans

	
	
Qaiwan City: Cooling Temperature Distribution Map between Open and Cellular Plans	**Qaiwan City:** Heating Temperature Distribution Map between Open and Cellular Plans

Cooling Temperature Range



Heating Temperature Range

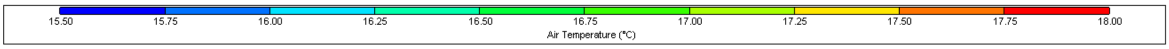


Figure 15: Zone-average indoor air temperature (°C) for the open- and cellular-plan configurations during representative heating and cooling period (Researcher).

Note: The maps represent EnergyPlus zone-average air temperatures and do not represent spatial airflow or CFD results.