

Building Form and Transmission Heat Loss at Constant Volume: Testing Five Geometric Hypotheses Under Astana Winter Conditions

Karina Kim¹; Danil E. Shafner²

¹Author, ²Supervisor

¹National School of Physics and Mathematics, Astana, Kazakhstan

²National School of Physics and Mathematics, Astana

Publication Date: 2026/10/22

Abstract: Compact buildings lose less heat. That much is textbook. Less clear is how much less, which part of the geometry does the work, and where the rule stops holding. I wrote down five quantitative predictions before running any numbers and tested them with a steady-state model ($Q = U \cdot A \cdot \Delta T$) of four residential plan forms with the same footprint (200 m²) and volume (1,000 m³): a square, a 1:4 rectangle, an L-shape and a U-shape with an open courtyard. Temperature differences of 40–55 K bracket Astana's design winter (indoor 20 °C, outdoor –31.2 °C, $\Delta T = 51.2$ K). Heat loss is not proportional to perimeter: walls make up only 41% of the square's envelope, so the rectangle's 25% longer perimeter added 10.4% to the loss, as predicted. Perimeter, not outline, drove the result. The rectangle and the L-shape differed by 0.5%, while the U-shape, whose bounding box is as compact as the L-shape's, lost 24.5% more than the square, and still lost 2.5% more if its courtyard walls lost no heat at all. At constant volume the best storey count always sat next to the continuous optimum $V^{1/3}/h_0$, but it was not always the nearest integer, so that prediction failed in narrow ranges. The optimal height itself moved from 10 m to 6.7 m once wall, roof and floor U-values were allowed to differ. All results are calculated values for idealised buildings, not measurements.

Keywords: Building Form; Surface-to-Volume Ratio; Transmission Heat Loss; Thermal Envelope; Courtyard; Cold Climate; Astana.

How to Cite: Karina Kim; Danil E. Shafner (2026) Building Form and Transmission Heat Loss at Constant Volume: Testing Five Geometric Hypotheses Under Astana Winter Conditions. *International Journal of Innovative Science and Research Technology*, 11(10), 1290-1299. <https://doi.org/10.38124/ijisrt/26oct453>

I. INTRODUCTION

➤ Background and Question

Buildings used about 31% of the world's final energy in 2019, and residential buildings accounted for 70% of that [1]. In a cold climate, heating takes a large share. Astana is a clear case: the national building-climatology code gives it a heating period of 209 days with a mean temperature of –6.3 °C, and a design temperature of –31.2 °C for the coldest five days [2]. Under these conditions, measures that cut heat loss before any heating equipment is chosen are worth the most [3].

Insulation and glazing get most of the attention, but plan form comes first, and it is the one decision that cannot be reversed later. Existing housing, such as the Soviet-period blocks of Almaty that are now being modernised [4], can get a new envelope but not a new footprint. The usual measure of compactness is the surface-to-volume ratio S/V , the envelope area divided by the enclosed volume [5, 6]. A smaller S/V means less surface to lose heat through. Studies that compare

forms mostly rely on energy simulation or specialised software [7, 8, 9]. That is right for real design, but it hides the arithmetic from anyone who wants to see why one form beats another.

So take two buildings with the same volume, the same U-values and the same indoor and outdoor temperatures. How much does plan shape change the heat loss, and what limits the answer? “Compact is better” is only a ranking, and a ranking follows from $Q = U \cdot A \cdot \Delta T$ whatever the numbers are, so on its own it tests nothing. What a calculation can add is magnitudes and boundaries. How much does a longer perimeter cost? When does an elaborate outline stop mattering? Where does stacking floors stop helping? I therefore organised the study around five hypotheses, each with a numerical prediction fixed before the calculation and an outcome that would count against it.

➤ *Aim*

To test five predictions about how plan form, courtyard exposure and storey count change the calculated transmission heat loss of a building of fixed volume, using calculations that a reader can repeat by hand.

➤ *Hypotheses*

Table 1 lists the hypotheses with the result that would refute each. Sections 3.4 and 4 give the derivations and the tests.

Table 1 Hypotheses, Predictions and Refutation Criteria.

ID	Prediction (stated before calculation)	Refuted if
H1	Q is affine, not proportional, in perimeter P . A relative change in P changes Q by the wall share of the envelope times that change (0.414 for the square), so a 25% longer perimeter (form B) raises Q by about 10.4%.	B is not about 10.4% above A, or the points do not fall on one straight line.
H2	At equal perimeter, outline shape does not matter: B and C (perimeters within 1%) differ in Q by less than 1%. A form with a compact bounding box but an indented outline (D) loses at least 20% more than the square.	B and C differ by 1% or more, or D is less than 20% above A.
H3	At constant volume the best integer number of storeys is the integer nearest to $n^* = V^{1/3}/h_0$, so it depends on storey height h_0 .	For any h_0 , the best integer is not the nearest one.
H4	The U-shape is worse than the square however well the courtyard is sheltered. It is worse than B and C only if courtyard walls lose more than about a third as much per m^2 as exterior walls.	The U-shape with a fully sheltered courtyard has an envelope no larger than the square's.
H5	The optimal total height is $H^* = (c/2U_w)^{2/3}V^{1/3}$, where $c = U_{\text{roof}} + g \cdot U_{\text{floor}}$. With equal U-values and $g = 1$ it is 10 m. Better roof insulation or a damped floor loss lowers it.	Numerical minimisation gives a height that differs from the formula by more than 0.1 m.

II. RELATED WORK

➤ *Form and Heat Demand*

Studies that compare compact and elongated forms agree on the direction of the effect. Marincu and colleagues [7] modelled three existing buildings with different A/V ratios, using 2D thermal-bridge modelling and the PHPP tool, and found that a higher A/V went with larger heat losses and a higher heating demand. Three buildings cover a narrow range of forms, so the result is a pointer rather than a rule. Straube [6] compared compactness indicators geometrically, without simulation, for houses and offices. He found that the penalty for an elongated form shrinks as buildings get bigger: for large buildings, about 10% of total energy use separates a compact square from a long narrow one. He also noted that pure geometry ignores what elongated forms offer for daylight and natural ventilation. Koźniewski [5] assesses compactness indicators for single-family houses at the initial design stage, which is the stage this paper is aimed at.

➤ *What Else Competes with Form*

Form is one factor among several. He and colleagues [10] simulated courtyard-type office buildings in China's hot-summer, cold-winter region and found that window U-value explained nearly 60% of the variation in heating energy, a reminder that envelope quality can outweigh shape. Araj [11] looks at the surface-to-volume ratio from the other side: a larger envelope loses more heat but also collects more solar energy, so the best form depends on what is being optimised. Stamenković and colleagues [12] study the shape factor for space cooling in buildings with green roofs, which shows that heating is only one of the demands form has to serve. At urban scale, Rode and colleagues [8] relate morphology to residential heat-energy demand across cities. Wang and colleagues [9], who study commercial blocks in a severe-cold region, cite earlier work putting the influence of urban

morphology on building energy use at 10–30% or more. That range concerns urban layout in commercial districts, not single houses, and I take it second-hand, so I use it only as a sign that morphology can matter.

➤ *Climate Inputs*

Climate data come from the national building-climatology code [2]: a heating period of 209 days with a mean of -6.3°C , a January mean of -15.1°C (Table 3.3 of the code), and a design temperature of -31.2°C for the coldest five-day period with probability 0.92. These are different quantities for different jobs. The design temperature is used to size heating systems and sets the peak heat loss; the monthly mean only describes typical weather. This paper uses the design value because the quantity it calculates is a heat-loss rate.

➤ *Gap*

Most of this work uses simulation. I did not find a calculation that a reader can check line by line for standard residential forms at a fixed volume under Astana's conditions. That is the gap, and I do not claim more. The geometry and the physics here are not new, and $Q = U \cdot A \cdot \Delta T$ is textbook. What the paper adds is a set of numerical predictions, tested in the open, about how large the effects of shape actually are.

III. METHOD

➤ *Design*

The study is a calculation-based comparison. There are no participants and no measurements; the “sample” is four hypothetical footprints plus a varying number of storeys. One variable changes at a time and everything else stays fixed (Table 2).

Table 2 Fixed and Varied Model Parameters.

Parameter	Value
Volume V	1,000 m ³
Footprint area A_f (single storey)	200 m ²
Storey height h (baseline)	5 m (also 3, 3.5 and 4 m in the storey tests)
U-value, walls, roof and floor	0.25 W/(m ² ·K) baseline; 0.20 and 0.35 as scenarios
Indoor temperature	20 °C
Temperature difference ΔT	55 K baseline (outdoor −35 °C); 51.2 K design (−31.2 °C); 40 and 50 K

➤ Choice of ΔT

The baseline $\Delta T = 55$ K (outdoor −35 °C) is a round, slightly severe scenario that I chose before looking up the official value. The design temperature of −31.2 °C [2] gives $\Delta T = 51.2$ K, which I report as a separate scenario (Table 7). Q is linear in ΔT , so the choice changes the magnitudes by about 7% and changes nothing else.

➤ Geometries

Form A is a 14.14 m square. Form B is a 1:4 rectangle of 28.28 × 7.07 m. Form C is an L-shape: a 20 × 15 m

rectangle with a 10 × 10 m notch at one corner. Form D is a U-shape: the same 20 × 15 m outline with a 10 × 10 m notch cut from the middle of one long side, which leaves two 5 × 15 m wings and a 10 × 5 m base (Figure 1). All four have an area of exactly 200 m². For the U-shape I checked this twice, by decomposition (75 + 75 + 50 m²) and with the shoelace formula. The courtyard is open to the sky, so its three walls (30 m in total) count as envelope, and its ground is not counted as floor.

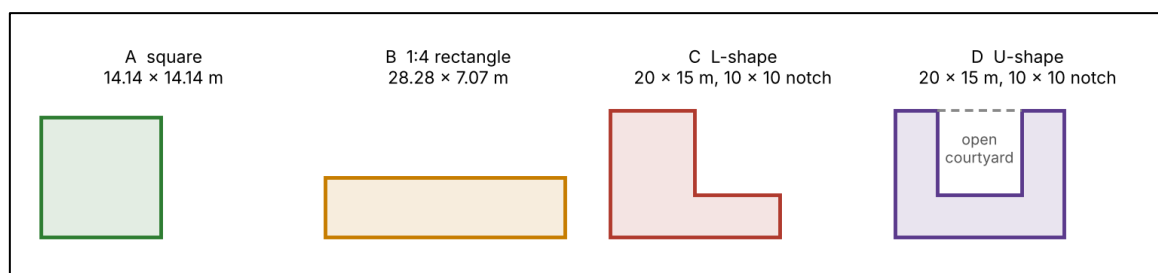


Fig 1 Footprints of Forms A–D, Drawn to the Same Scale. Each Has an Area of 200 m².

➤ Calculation

For each form the envelope area is walls plus roof plus ground floor,

$$A = P \cdot h + 2A_f \quad (1)$$

Where P is the perimeter, and the transmission heat loss at steady state is

$$Q = U \cdot A \cdot \Delta T. \quad (2)$$

The product $U \cdot A$ of an element is its heat-loss coefficient [13]. (H1) Differentiating (1) gives $dA/A = w \cdot dP/P$, with the wall share

$$w = P \cdot h / A. \quad (3)$$

With equal U and ΔT , w is also the elasticity of Q with respect to P . For the square, $w = 282.84/682.84 = 0.414$. (H3) For the storey tests the storey height h_0 is fixed, the total height is $H = n \cdot h_0$, and the square footprint per floor is V/H . Only the ground floor and the top roof are envelope, because internal slabs separate heated space from heated space:

$$A(n) = 4 \cdot \sqrt{(V/H) \cdot H} + 2V/H. \quad (4)$$

Setting the derivative to zero gives the continuous optimum $n^* = V^{1/3}/h_0$. (H5) If wall, roof and floor have

different U-values, and the floor sees a fraction g of the air temperature difference ($g < 1$ if the ground is warmer than the outdoor air), then,

$$Q(H) = \Delta T [4U_w \sqrt{V \cdot H^{1/2}} + c \cdot V/H], \quad c = U_{\text{roof}} + g \cdot U_{\text{floor}}, \quad (5)$$

Which is smallest at $H^* = (c/2U_w)^{2/3} V^{1/3}$. (H4) For the U-shape I let the courtyard walls lose a fraction f of what an exterior wall loses per m². $f = 1$ is full exposure and $f = 0$ is a courtyard that loses nothing. With 60 m of exterior wall and 30 m of courtyard wall, $A_D(f) = 60h + 2A_f + 30h \cdot f = 700 + 150f$ m² for $h = 5$ m.

All numbers were produced by one Python script (Appendix B), which also checks the closed-form results against a brute-force minimisation.

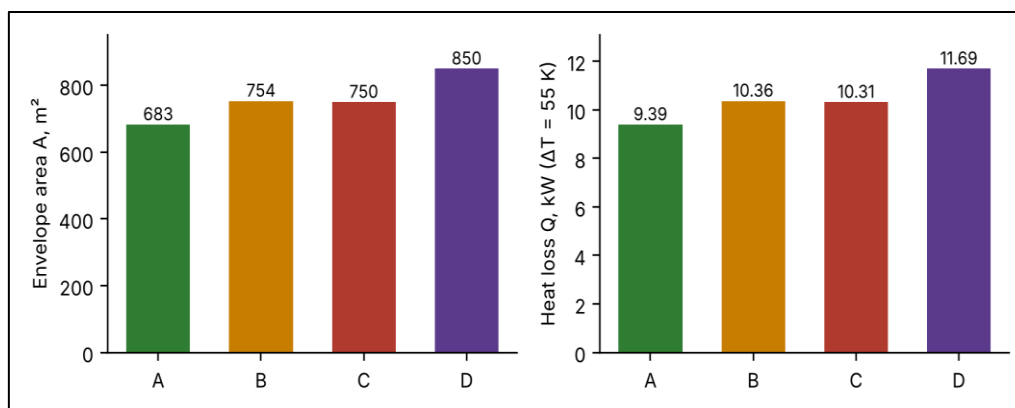
IV. RESULTS

➤ Baseline Forms

Table 3 gives the baseline results for $U = 0.25$ W/(m²·K) and $\Delta T = 55$ K (Figure 2). The square has the shortest perimeter and the smallest envelope, so it has the lowest loss. Forms B and C have almost the same perimeter, 70.71 m and 70.00 m, and lose about 10% more. The U-shape loses 24.5% more.

Table 3 Baseline Results ($U = 0.25 \text{ W}/(\text{m}^2 \cdot \text{K})$, $\Delta T = 55 \text{ K}$).

Form	P, m	A, m ²	S/V	Q, W	Q vs. A
A square	56.57	682.84	0.683	9,389.1	—
B 1:4 rectangle	70.71	753.55	0.754	10,361.4	+10.36%
C L-shape	70.00	750.00	0.750	10,312.5	+9.83%
D U-shape	90.00	850.00	0.850	11,687.5	+24.48%

Fig 2 Envelope Area (left) and Calculated Heat Loss (Right) of Forms A–D at $\Delta T = 55 \text{ K}$.

➤ H1: Heat Loss is Affine in Perimeter

Before calculating, I predicted that the 25% longer perimeter of form B would raise the loss by $0.414 \times 25.0\% = 10.4\%$. The calculation gives +10.36%. The same line predicts the other two forms: form C has a 23.7% longer perimeter and should lose 9.83% more (observed +9.83%); form D has a 59.1% longer perimeter and should lose 24.48% more (observed +24.48%). All four points fall on one straight line (Figure 3). If Q were proportional to perimeter, form B

would have been 25% worse, 2.4 times the true figure. H1 is supported.

This follows directly from equation (1), so the test confirms the algebra more than it discovers anything. What it adds is the size of the effect: roof and floor are 400 m², or 59% of the square's envelope, and they do not care about shape at all. Only the wall term moves.

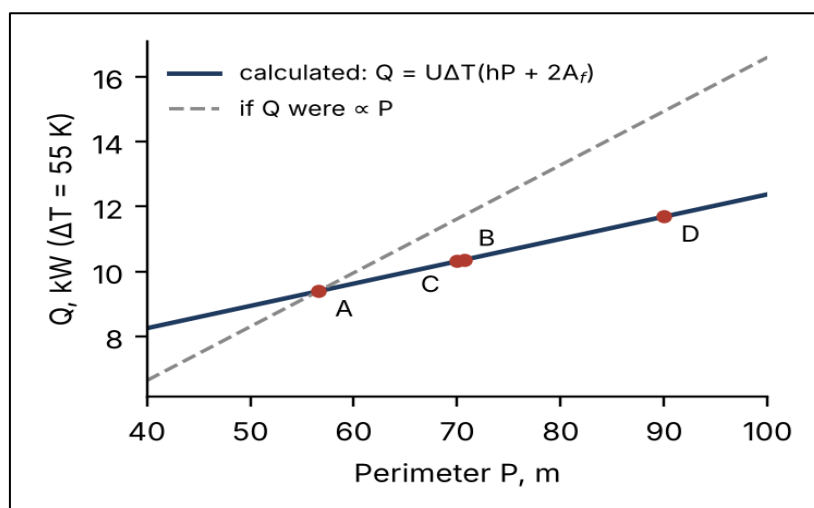


Fig 3 Heat Loss Against Perimeter for Forms A–D. The Solid Line is Equation (1) with Equation (2). The Dashed Line Shows what Proportionality Through the Square Would Give.

➤ H2: Perimeter Matters More Than Outline

Forms B and C look nothing alike, one a long strip and the other an L, but their perimeters differ by 0.71 m. The predicted difference in loss is $0.71 \times 5 / 750 = 0.47\%$, and the calculation gives 0.47% (10,361.4 W against 10,312.5 W). The L-shape's perimeter equals that of its $20 \times 15 \text{ m}$ bounding rectangle (70 m), because a corner notch replaces two edges with two edges of the same total length.

The U-shape has the same $20 \times 15 \text{ m}$ bounding box, so by eye it looks as compact as the L-shape. Its perimeter is 90 m, because the notch trades 10 m of outer edge for 30 m of edge (10 + 10 + 10 m) and adds 20 m. I predicted a loss at least 20% above the square. It is 24.48% above. H2 is supported. The bounding box is a poor guide, and the actual perimeter is the number to check.

➤ *H3: Storey Count at Constant Volume*

Table 4 and Figure 4 show the storey experiment. At $h_0 = 5$ m the envelope falls from 682.84 m² at one storey to 600.00 m² at two (Q from 9,389 W to 8,250 W) and rises to

623.23 m² at three (8,569 W); the analytical optimum is exactly $n^* = 2.0$. At $h_0 = 3$ m it is still falling at three storeys (885.76, 643.17, 601.70 m²), in line with $n^* = 3.33$. More storeys are not automatically better.

Table 4 Envelope Area (m²) at Constant Volume $V = 1,000$ m³ for One to Three Storeys, and the Best Integer.

h_0 , m	n^*	A(1)	A(2)	A(3)	Best integer n
3.0	3.33	885.76	643.17	601.70	3
3.5	2.86	808.07	620.38	600.35	3
4.0	2.50	752.98	607.77	604.84	3
5.0	2.00	682.84	600.00	623.23	2

The best integer was always one of the two integers next to n^* . I checked this for every h_0 from 2.00 to 10.00 m in steps of 0.01 m (801 values) and found no exception. The stronger prediction, that it is the *nearest* integer, failed in 63 of the 801. The envelope curve is steeper on the few-storey side, so the switch from k to $k + 1$ storeys happens before n^* reaches $k + \frac{1}{2}$: at $n^* = 1.40, 2.44, 3.46$ and 4.47 instead of 1.5, 2.5,

3.5 and 4.5. For example, at $h_0 = 4.05$ m, $n^* = 2.47$ rounds to two storeys, but three storeys have the smaller envelope (605.5 m² against 606.9 m²). The penalty for rounding wrongly is usually tiny and is largest, 2.4%, for n^* between 1.4 and 1.5. H3 is refuted as stated (nearest integer) and holds in the weaker form (floor or ceiling of n^*).

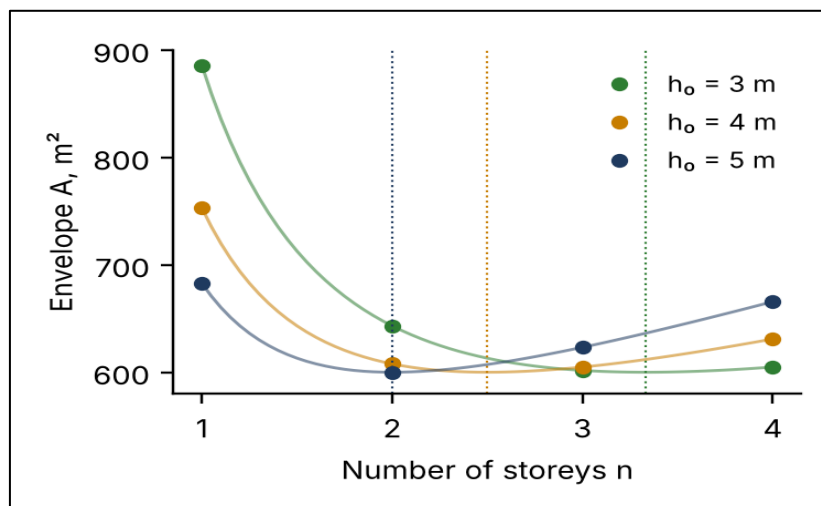


Fig 4 Envelope Area Against Number of Storeys for three Storey Heights. Curves are the Continuous Version of Equation (4); Dotted Lines Mark n^* .

➤ *H4: How Much Does the Courtyard Matter?*

The 30 m of courtyard wall add 150 m² to the U-shape's envelope at full exposure. Even with $f = 0$, that is, courtyard walls that lose nothing, the envelope is 700 m², which is 2.5% above the square's 682.84 m². The reason is that the U-shape has 60 m of true exterior wall, more than the square's 56.57

m, before the courtyard is counted at all. The U-shape equals form C at $f = 0.333$ and form B at $f = 0.357$ (Table 5, Figure 5). It is therefore the worst of the four forms only if its courtyard walls lose more than about a third as much per m² as exterior walls. H4 is supported.

Table 5 U-Shape Envelope and Heat Loss Against Courtyard Exposure f ($\Delta T = 55$ K, $U = 0.25$).

f	A_D , m ²	Q_D , W	vs. square
0.00	700.0	9,625.0	+2.51%
0.25	737.5	10,140.6	+8.00%
0.50	775.0	10,656.3	+13.50%
0.75	812.5	11,171.9	+18.99%
1.00	850.0	11,687.5	+24.48%

The model cannot say what f is in a real courtyard. It would stand for shelter from wind, solar gain on courtyard walls, or a warmer microclimate, and I have no data for any of them. I treat it as an open parameter.

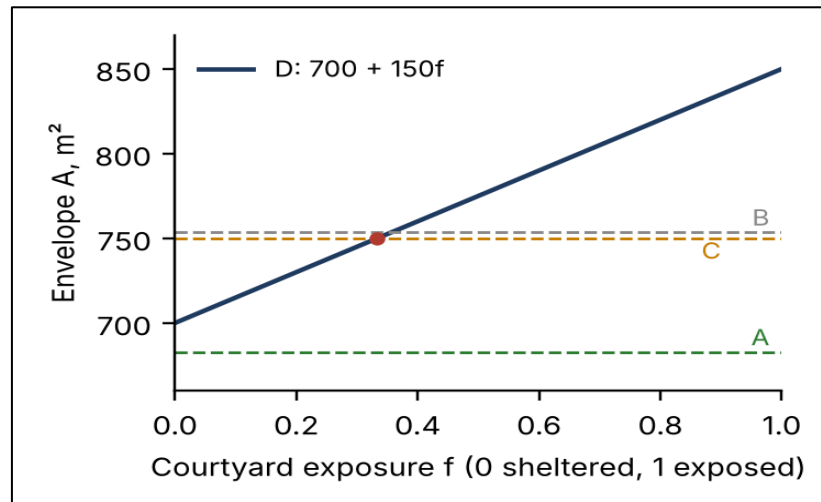


Fig 5 Envelope Area of the U-Shape (form D) Against Courtyard Exposure f . The Dot Marks the Crossing with Form C at $f = 0.333$.

➤ *H5: the Optimal Height Depends on the U-Values*

Brute-force minimisation of equation (5) on a 1 mm grid matched the closed-form H^* within 0.01 m in all four cases of Table 6, well inside the 0.1 m refutation limit, so H5 is supported. This is a check of a derivation, not an empirical test. With equal U-values and a floor that sees the full ΔT , H^*

= 10 m, which is $V^{1/3}$ and two storeys of 5 m. A floor that sees half the air-to-air difference moves it to 8.25 m; a roof with a U-value of 0.15 instead of 0.25 (floor factor kept at 0.5) moves it to 6.71 m, barely more than one storey of 5 m. Better walls than roof push it the other way, to 14.06 m.

Table 6 Optimal Total Height H^* for Different U-Values ($W/(m^2 \cdot K)$) and Floor Factors g .

Case	U_w	U_r	U_f	g	H^*, m	$n^* (h_0 = 5 m)$	$n^* (h_0 = 3 m)$
Equal U, floor at full ΔT	0.25	0.25	0.25	1.0	10.00	2.00	3.33
Equal U, floor at half ΔT	0.25	0.25	0.25	0.5	8.25	1.65	2.75
Roof better than walls	0.25	0.15	0.25	0.5	6.71	1.34	2.24
Walls better than roof	0.15	0.25	0.25	1.0	14.06	2.81	4.69

The curves are shallow near their minima (Figure 6). In the equal-U case, going from the optimum of 10 m to three 5 m storeys (15 m) raises the loss only from 8,250 W to 8,569 W, or 3.9%. A wrong storey count costs little. A wrong form can cost 10–25%.

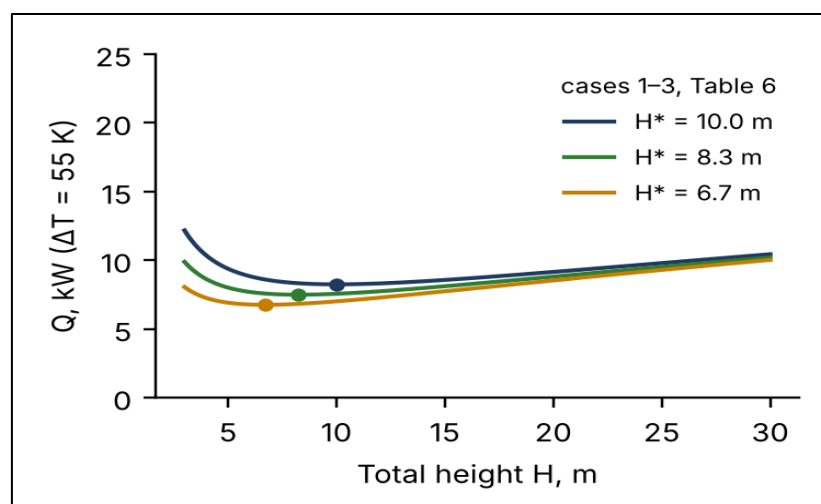


Fig 6 Heat Loss Against Total Height for Cases 1–3 of Table 6. Dots Mark H^* .

➤ *Sensitivity to ΔT and U*

Because Q is linear in both U and ΔT , the percentage differences between forms are the same in every scenario and

the ranking cannot change. Table 7 is given for the magnitudes only, including the official design condition ($\Delta T = 51.2 K$).

Table 7 Calculated Q (W) Under the Scenarios.

Scenario	A	B	C	D
$\Delta T = 40$ K, $U = 0.25$	6,828.4	7,535.5	7,500.0	8,500.0
$\Delta T = 50$ K, $U = 0.25$	8,535.5	9,419.4	9,375.0	10,625.0
$\Delta T = 51.2$ (design) K, $U = 0.25$	8,740.4	9,645.5	9,600.0	10,880.0
$\Delta T = 55$ K, $U = 0.25$	9,389.1	10,361.4	10,312.5	11,687.5
$\Delta T = 55$ K, $U = 0.20$	7,511.3	8,289.1	8,250.0	9,350.0
$\Delta T = 55$ K, $U = 0.35$	13,144.7	14,505.9	14,437.5	16,362.5

V. DISCUSSIONS

Table 8 sums up the outcomes. Four hypotheses were supported and one was refuted in its strict form.

Table 8 Outcome of the Five Tests.

ID	Outcome	Key number
H1	Supported	B: predicted +10.36%, observed +10.36%; C and D also on the line
H2	Supported	B vs. C differ by 0.47%; D is +24.48% despite the compact bounding box
H3	Refuted as stated	Best integer is floor or ceiling of n^* in 801 of 801 cases; nearest in 738 of 801
H4	Supported	D with $f = 0$ is +2.51%; D equals C and B at $f = 0.333$ and 0.357
H5	Supported	Closed form and numerical optimum agree within 0.01 m

➤ What Shape Actually Changes

In every form the roof and floor add up to 400 m², so the whole spread between the four forms, 682.84 to 850.00 m², is a wall-area effect. That has a consequence the equal- U model hides. If the walls leak more than the roof, as they do once windows are included (the study of He et al. [10] points the same way, with window U -value dominant), then walls carry more than 41% of the heat loss and perimeter matters more than I found. If the roof is better insulated than the walls, H^* falls as well. I expect both effects but did not test them.

➤ The Courtyard

The U-shape result is a bound, not a prediction. At full exposure, the U-shape pays 24.5%. With a perfectly sheltered courtyard it still pays 2.5%. Real courtyards sit somewhere between, and where depends on wind, sun and microclimate that this model does not contain. A courtyard also brings daylight and ventilation, which this paper does not price.

➤ Peak Power and Annual Energy

The ΔT of 51.2–55 K gives the peak loss rate, which sizes the heating system. Annual energy follows the heating season. Using the 209 days at a mean of -6.3 °C and an indoor 20 °C gives about 5,500 K·days, and transmission-only loss through the walls, roof and floor at $U = 0.25$ is then about 22.5 MWh a year for the square and 28.0 MWh for the U-shape. These are order-of-magnitude figures, since they ignore windows, ventilation and gains. The ranking and the percentage gaps are the same as at peak.

➤ Comparison with Other Studies

My 10–25% differences are for transmission loss alone, with equal U -values. The effects reported by Marincu et al. [7], who include thermal bridges and annual heating demand, and by Straube [6], whose roughly 10% for large buildings is a total-energy figure, answer different questions and should not be compared with mine number for number. The qualitative agreement is that compact forms need less heat

and that the advantage shrinks relative to other factors in larger buildings.

VI. LIMITATIONS

The model is steady-state and covers only transmission through walls, roof and ground floor. It leaves out infiltration, ventilation, thermal bridges, windows, solar and internal gains, orientation and wind. One U -value is used for all elements except in H5, and the ground floor sees the full ΔT in the baseline, which overstates floor losses. The parameters f and g and the U -values in Table 6 are scenarios, not measurements. The storey tests ignore slabs, stairs, structure and cost, and the forms are idealised. Astana enters only through ΔT and the heating season, and nothing in the geometry is specific to Astana. The results were not compared with dynamic simulation or with measured buildings.

VII. CONCLUSION

Geometry changes transmission heat loss by a real but bounded amount, and it does so through the walls only. A 59% longer perimeter (the U-shape) costs 24.5%; a 25% longer one (the strip) costs 10.4%. The length of the boundary matters more than the look of the outline. The U-shape stays worse than the square even when the courtyard walls lose no heat. For storeys, the optimum is flat, depends on storey height and on how well the roof, walls and floor are insulated, and is not always the nearest whole number to the continuous optimum.

Next steps are to replace the single U -value with values from the thermal-protection code [14], add windows, measure or simulate courtyard exposure f , and compare the results with a dynamic energy simulation.

ACKNOWLEDGEMENTS

I thank my supervisor, Danil E. Shafner, for his questions and for giving me room to work things out myself.

➤ Statement on the Use of AI

An AI assistant (Perplexity Computer) was used for the original calculation scripts, the Excel workbook and the layout of the first version of this paper. For this version, an AI assistant (Claude, Anthropic) was used to restructure the paper around testable hypotheses, edit the language, correct errors in citations and cross-references, and write the script *heat_loss_model_v4.py*. The author is responsible for the content, has checked the calculations, and can reproduce every number from the script described in Appendix B.

REFERENCES

- [1.] L. F. Cabeza et al., “Buildings,” in *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the IPCC*. Cambridge University Press, 2022. doi:10.1017/9781009157926.011
- [2.] Committee for Construction and Housing, Ministry for Investments and Development of the Republic of Kazakhstan, SP RK 2.04-01-2017: Building Climatology, Order No. 312-NK, 2017. <https://igis.kz/images/snip/stroitelnye-normativy/sp-rk-2.04-01-2017-stroitelnaya-klimatologiya.pdf>
- [3.] S. N. Al-Zubaidy, S. Tokbolat, R. Tokpatayeva, “Passive design of buildings for extreme weather environment,” *Int. J. Renewable Energy Dev.*, vol. 2, no. 1, pp. 1–11, 2013. doi:10.14710/ijred.2.1.1-11
- [4.] K. Murzabayeva, E. Lapshina, and A. Tuyakayeva, “Modernization of the living environment space using the example of an urban array of residential buildings from the Soviet period in Almaty,” *Buildings*, vol. 12, no. 7, art. 1042, 2022. doi:10.3390/buildings12071042
- [5.] E. Koźniewski, “Assessment of building compactness at initial design stage of single-family houses,” *Energies*, vol. 18, no. 13, art. 3569, 2025. doi:10.3390/en18133569
- [6.] J. Straube, “BSD-061: The function of form—building shape and energy,” Building Science Corporation, 2012. <https://buildingscience.com/documents/insights/bsi-061-function-form-building-shape-and-energy>
- [7.] C. Marincu, D. Dan, and L. Moga, “Investigating the influence of building shape and insulation thickness on energy efficiency of buildings,” *Energy Sustain. Dev.*, vol. 79, art. 101384, 2024. doi:10.1016/j.esd.2024.101384
- [8.] P. Rode, C. Keim, G. Robazza, P. Viejo, and J. Schofield, “Cities and energy: urban morphology and residential heat-energy demand,” *Environ. Plann. B*, vol. 41, no. 1, pp. 138–162, 2014. doi:10.1068/b39065
- [9.] Y. Wang, W. Pan, and Z. Liao, “Impact of urban morphology on high-density commercial block energy consumption in severe cold regions,” *Sustainability*, vol. 16, no. 13, art. 5795, 2024. doi:10.3390/su16135795
- [10.] C. He, W. Tian, and Z. Shao, “Impacts of courtyard envelope design on energy performance in the hot summer–cold winter region of China,” *Buildings*, vol. 12, no. 2, art. 173, 2022. doi:10.3390/buildings12020173
- [11.] M. T. Araj, “Surface-to-volume ratio: how building geometry impacts solar energy production and heat gain through envelopes,” *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 323, art. 012034, 2019. doi:10.1088/1755-1315/323/1/012034
- [12.] M. Stamenković, M. Miletić, S. Kosanović, G. Vučković, and S. Glišović, “Impact of a building shape factor on space cooling energy performance in the green roof concept implementation,” *Therm. Sci.*, vol. 22, no. 1B, pp. 687–698, 2018. doi:10.2298/TSCI170425205S
- [13.] B. Anderson and L. Kosmina, *Conventions for U-value Calculations*, BR 443, 3rd ed. BRE, 2019. <https://www.cibse.org/media/wzrjrf3l/conventions-for-u-value-calculations.pdf>
- [14.] SN RK 2.04-07-2022 / SP RK 2.04-107-2022: Thermal Protection of Buildings, Order No. 233-NK, 2022. https://new-shop.ksm.kz/media/egfntd/ntdgo/2_04_07_2022.pdf

APPENDIX**APPENDIX A SUPPLEMENTARY GEOMETRY**

Table A1 lists the perimeter of the U-shape segment by segment.

Table A1 U-Shape Perimeter by Segment.

Segment	Length, m	Type
South wall	20	exterior
East wall	15	exterior
North, right wing	5	exterior
Courtyard, east	10	courtyard
Courtyard, base	10	courtyard
Courtyard, west	10	courtyard
North, left wing	5	exterior
West wall	15	exterior
Total	90	60 exterior + 30 courtyard

APPENDIX B REPRODUCIBILITY

All values come from *heat_loss_model_v4.py*, which needs only Python 3 (matplotlib is used for the figures). It computes the baseline and sensitivity tables, the storey tables, the tests of H1–H5, a shoelace check of the U-shape area, and a brute-force check of the closed-form optimum in H5. It writes the result tables as CSV files: *results_baseline.csv*, *results_sensitivity.csv*, *results_storeys.csv*, *h1_wall_share.csv*, *h3_storeys.csv*, *h3_switch_points.csv*, *h4_courtyard_exposure.csv*, *h5_generalised_optimum.csv* and *annual_transmission_energy_kWh.csv*, together with the six figures.