Comparative Analysis of Occupant Comfort, Energy Use and Thermal Performance of Two Houses Built as per Strict and Flexible Architectural Control on a V4 Road in Chandigarh.

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ABSTRACT

The different components of a building envelope such as covered area, windows and brick jalis, building materials, and shading devices regulate natural light, ventilation, and heat which impacts the occupants' visual and thermal comfort. The quality of light, ventilation, and heat gain depends on the amount of wall space provided for the windows which is expressed as the window-to-wall ratio (WWR), openings such as brick jalis, and shading elements. The design and utilisation of such components is mandated by architectural controls enforced by the local administration. This study focuses on the impact of these components of the building envelope on occupants' comfort and energy consumption. The study is based on occupant comfort, energy use, and thermal performance analyses of the two houses, situated on a V4 road in Chandigarh which is known for stricter architectural controls, which have been recently made flexible. Out of these two houses, the first house was constructed as per strict architectural controls proposed earlier by the Chandigarh administration and the other house was constructed as per flexible architectural controls introduced in 2008. The two houses have an identical orientation towards the southwest but differ in the permissible covered area, WWR, shading elements, and materials. Thermal comfort analysis, daylight analysis and energy consumption analysis will be done using tools such as Building information modelling (BIM) on Autodesk Revit 2022 and further simulation will be performed on on DesignBuilder 6.1.0.006 (EnergyPlus engine 8.9). The study intends to uncover the relationship between thermal and visual comfort and architectural controls.

INTRODUCTION

The Context – les sept voies

Le Corbusier, the architect and planner of the city Chandigarh, designed the city on the concept of les sept voies (the seven Vs), where the circulation and road network are labelled in a hierarchical order of the circulation from the roads entering the city to the roads leading up to the houses. The V1 are the regional highways leading into the city from the outside. The V2 are the major boulevards usually with 'Marg' in their names. The road coming from the capitol complex- Jan Marg, the northern and southern boundary roads- Uttar marg and Dakshin marg. These roads have all the major government offices and bhawans. V3 roads form the sector dividers, providing the grid pattern of the city, these roads are reserved for fast-moving motor traffic with no openings of the buildings towards the V3. The sector is thus planned to focus internally. Bisecting each sector from west to east are V4 or shopping streets. The shops are located only on the shady side of the road for comfort and for eliminating the necessity of frequent street crossing. Intersecting the V4 at two points would be a V5, a ring road distributing slow traffic within the sector. The V6 are the roads leading to the doors of the houses. The V7 are the pathways designed to carry pedestrians.[1]

Architectural control in Chandigarh

In the planned city of Chandigarh, earlier the architectural control in terms of material, plans and elevations was only applicable to the government housings and office buildings, shops-cum-flats on the V4 and V3 roads. Though, in 1963, after the development of the first sector (sector 22) the lack of any control on private housings resulted in haphazard designs, ornamentation, varied patterns of fenestrations, projecting balconies and uneven roof lines. This resulted in the formulation of laws applicable on all plot sizes up to 10 Marla (250square yards) in 1968 called 'Frame control' which fixed the extents, heights of party walls and top course connecting these. The only private houses to come under full architectural control were the houses opposite the V4 market streets in sectors 10, 11, 18, 19, 27, 28 [2]. The new law specified the heights, building lines, plans, elevations, brick jail designs and materials to be used[3]. The law was rigidly followed and monitored from 1968 to 2008 but this bye-law was lifted in addition to formulations of new laws.

Scope of study
In this paper, the scope of the study is restricted to the set of houses on V4 road in sector 28 which was earlier required to meet the elevation, material and planning specifications given by the Chandigarh administration till the amendment in the law of full architectural control in 2008. In this paper, the subject of study is one prototype of a Modern architecture house (H1), constructed between 1968, per architectural drawings mandated by the Chandigarh Administration and one Contemporary architecture house (H2) built after the 2008 mandate.

Rationale
The rationale for choosing these is to create a comparative analysis of the two in terms of occupant comfort (thermal comfort and visual comfort), window wall ratios, and energy consumption to arrive at a hypothesis if the lifting of the architectural control has enhanced or deteriorated the comfort and energy status quo. If it had, in case, deteriorated what measures can still be included as recommendations for the private constructor and owners. If it had been enhanced then a similar study can be done on government houses and such to analyse the different case scenarios.

Occupant Comfort Indicators and Standards
As per Section 8 of the National building code[4], Thermal comfort is the state under which a human body can maintain a normal body temperature without perceptible sweating. The thermal comfort of a person lies between TSI values of 25°C and 30°C with the optimum condition at 27.5 ° C.[5] [6]. There are many models for evaluation of thermal comfort, the ones being evaluated for this study are listed below

METHODOLOGY
The impact of components of the building like covered area, windows and brick jalis, building materials, and shading devices on occupants' comfort and energy consumption is well established. In order to only analyse the impact of building material specifications, permissible covered area, Window-wall-ratio (WWR) and shading devices on thermal comfort and energy use, buildings with identical orientation (southwest facing) are chosen. Since the location of the buildings is same, a single set of climatic data is used.
The methodology used to conduct the study is to model and simulate the houses using the data collected. Further, the analysis of occupant comfort is conducted using the secondary data (relative humidity, metabolic rate, clothing insulation, air temperature, air velocity, and mean radiant temperature) made available with the input of weather files and location coordinates. The building is modelled on Autodesk Revit using the Building Information Modelling and simulated using the inbuilt Revit to DesignBuilder plugin on EnergyPlus engine 8.9. The data required for the modelling were architectural plans, elevations, sections, and material specifications. The data needed for conducting the study has been made available from the office of the chief architect, Department of Architecture, Chandigarh for both houses. The material specification is provided in the Chandigarh bye-laws, for house 1 (H1) and in the drawings for house 2 (H2).

Site And Building Block
This study has been conducted on two residential buildings in Chandigarh (30° 44' 29.3352'' N and 76° 46' 5.0376'' E and 321 metres above sea level). The average annual maximum temperature of Chandigarh is 30.4 ° C and the average minimum temperature is 16.3 ° C. Average annual Rainfall is 107.0 cm. Values of Relative Humidity are about 53 % to 80% in the morning and 39% to 70 % in the afternoon. [12]

Table 1 Site Information

	Modern House (H1)	**Contemporary House (H2)**

Total	142.05 m^2	255.26 m^2
Conditioned Total	122.79 m^2	213.20 m^2
Unconditioned Total	19.25 m^2	42.05 m^2

Temperature Inputs
As the input data for the weather condition, the EnergyPlus weather file of the nearest city available (New Delhi) was used.

Simulation Model
Both the residences were modelled in Autodesk REVIT 2022 using the building information modelling (BIM) of the actual building block using the azimuth angle, wall properties, roof properties, glazing properties, occupant schedule, shading devices, etc. The simulation was carried out on Designbuilder using EnergyPlus (version 8.9.0) building simulation program. Since both the houses are located in a row housing block, the property party walls are set as adiabatic in the simulation adjacency parameters. Climatic data used for conducting the simulation is shown in *Table 2 Climatic Data Summary*

Table 2 Climatic Data Summary

	Maximum Dry Bulb [C]	**Daily Temperature Range [delta C]**	**Humidity Value**
Summer Design Day - July	40.20	8.40	25.20
Summer Design Day - Aug	37.50	7.70	26.50
Summer Design Day - Sep	36.90	9.50	24.30
Winter Design Day - Jan	6.20	0.00	6.20

Layer-by-layer construction of the exterior wall, interior wall, various slabs and the roof has been given in the *Table 3 Model Input Parameters* as well as Figure 1 *Layer-By-Layer Construction (Outside To Inside)*. Once the modelling was completed in REVIT, an analytical model was created using building elements which transforms the spaces and rooms into analytical spaces using the building components' information. This analytical model was then exported to DesignBuilder (version 6.1.0.006) by using the Revit to DesignBuilder export plugin.
The settings used for exporting the model to DesignBuilder were: - Building geometry was exported using the setting “Complex with shading surfaces”; for building envelope “identify exterior elements”; Building service “Split system with natural ventilation”; Building type “multifamily”; Operating schedule “Residential”.
The details of HVAC system used in the house as well as the settings used for the simulation are mentioned in the *Table 4 HVAC details.* The details of building envelope and window to wall ratios for both houses is given in Table 5.

Table 3 Model Input Parameters

	Properties	**Modern House (H1)**	**Contemporary House (H2)**
Exterior Wall	*Construction*	10 mm Plaster + 345 mm Brick + 10mm Plaster	10 mm Plaster + 230mm Wall + 10mm Plaster
	Thickness	0.365	250 mm

	U-value (W/(m2.k))	1.416	1.830
Interior Wall	*Construction*	10 mm Plaster + 230mm Wall + 10mm Plaster	10 mm Plaster + 115 mm Wall + 10mm Plaster
	Thickness	250 mm	135 mm
	U-value (W/(m2.k))	1.830	2.585
Roof Slab	*Construction*	50 mm Roof Tile + 12.5 mm Screed + 100 mm	20 mm Roof Tile + 10 mm Screed + 100 mm
		Concrete slab + 10 mm Plaster	Concrete slab + 10 mm Plaster
	Thickness	172.5 mm	140 mm
	U-value (W/(m2.k))	2.881	3.276
Ground floor Slab	*Construction*	40 mm Granite+ 12.5 mm Screed + 100 mm Concrete slab + 300 mm Clay	40 mm Granite+ 12.5 mm Screed + 100 mm Concrete slab + 300 mm Clay
	Thickness	452.5 mm	452.5 mm
	U-value (W/(m2.k))	1.658	1.719
Internal Slabs	*Construction*	40 mm Granite+ 12.5 mm Screed + 100 mm Concrete slab + 10 mm Clay	40 mm Granite+ 12.5 mm Screed + 100 mm Concrete slab + 10 mm Clay
	Thickness	162.5 mm	162.5 mm
	U-value (W/(m2.k))	3.313	3.313
Windows	*Window Wall Ratio*	8.92 %	26.17
	Frame Width	40 mm	40 mm
	Frame U-Value (W/(m2.k))	3.633	3.633
	Glass U-Value (W/(m2.k))	3.790	3.790
	VLT	0.811	0.811
	SHGC	0.72	0.72

Table 4 HVAC details

HVAC			
	Properties	Modern House (H1)	Contemporary House (H2)
HVAC System	System Type	Split + Separate Mechanical Ventilation	Split + Separate Mechanical Ventilation
	Setpoint Temp °F	25 deg C	25 deg C

Table 5 Building envelope details of H1 and H2

BUILDING ENVELOPE										
	Total		**North (315° to 45°)**		**East (45° to 135°)**		**South (135° to 225°)**		**West (225° to 315°)**	
	H1	**H2**	**H1**	**H2**	**H1**	**H2**	**H1**	**H2**	**H1**	**H2**
Gross Wall Area [m²]	326.63	368.69	58.45	39.55	89.16	136.85	89.86	55.45	89.16	136.85
Window Opening Area [m²]	29.13	96.74	3.76	10.10	6.75	37.72	9.69	14.27	8.93	34.64
Gross Window-Wall Ratio [%]	8.92	26.24	6.44	25.55	7.57	27.56	10.79	25.74	10.01	25.31

RESULTS

Thermal comfort summary of Fanger thermal comfort model

As per the Fanger model of thermal comfort as shown in Figure 2: PMV- PPD graph for H1 and H2 and Table 9 Fanger PMV-PPD Model for H1 and H2, the PMV ranges month of January (-0.91 and -0.88 respectively) and June (1.66 and 1.52 respectively) have the extreme ranges of the PMV index for both the houses, in which +3 translates as too hot, while -3 translates as too cold. On the PPD scale, H1 (Built-in 1968) has the highest percentage of dissatisfied people in June (54.14 %) and the lowest percentage of dissatisfied people in November (8.78 %) whereas House 2 (Built-in 2008) has the highest percentage of dissatisfied people in June (52.37 %) and lowest percentage of dissatisfied people in February (15.62 %). Predicted percentage of dissatisfied (PPD) in H1 and H2 in the run period is 29.2% and 33.9% respectively.

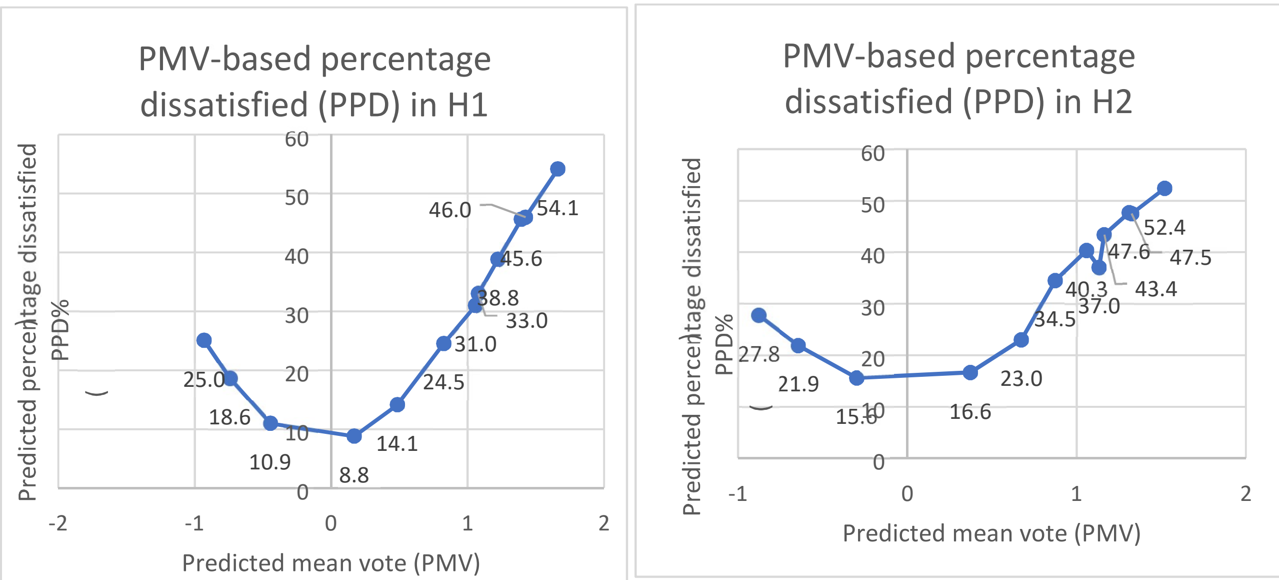

Figure 2: PMV- PPD graph for H1 and H2

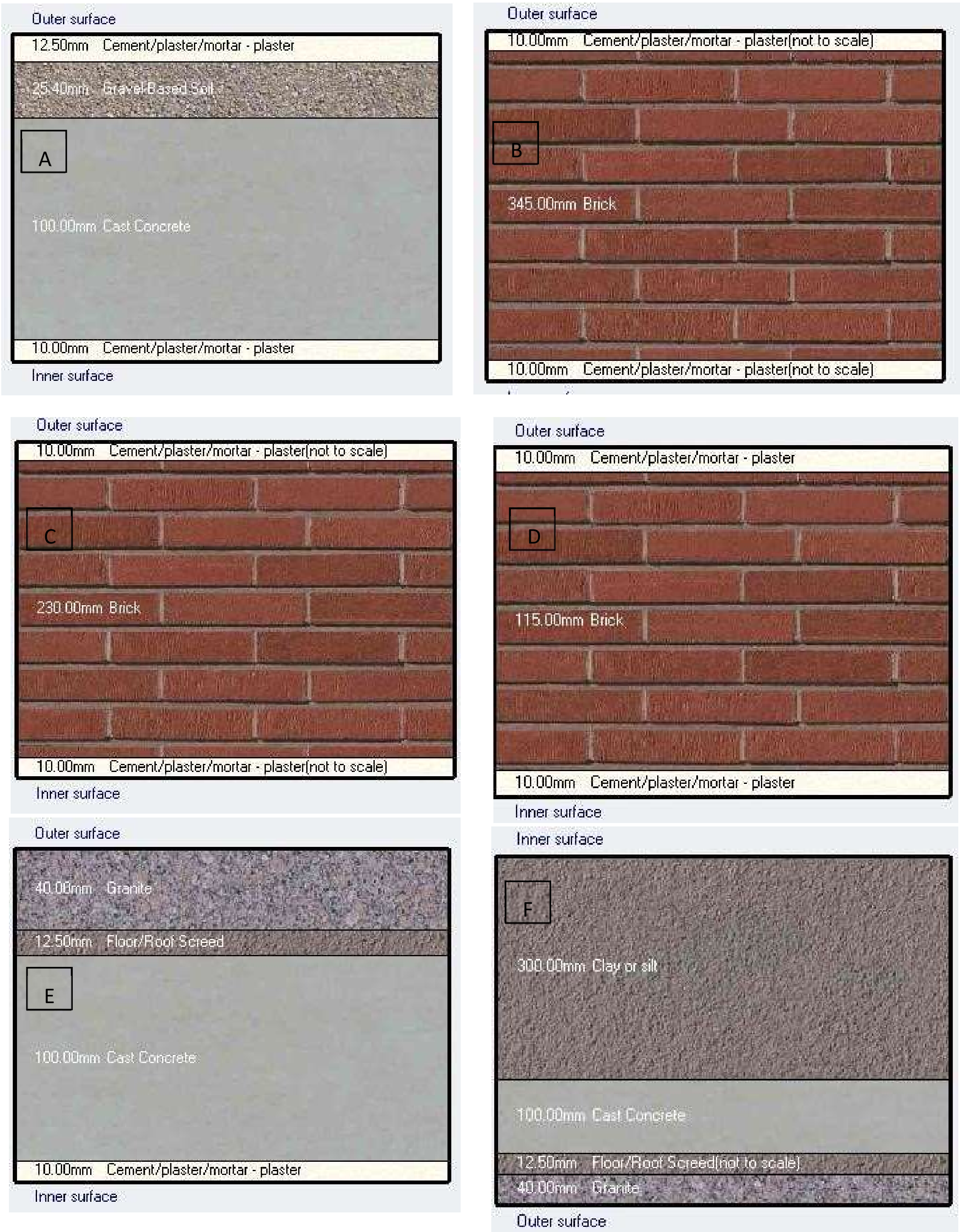

Figure 1 Layer-By-Layer Construction (Outside To Inside)

(A) Roof Slab
(B) 13.5” Thick Wall
(C) 9” Thick Wall
(D) 4.5” Thick Wall
(E) Internal Floor Slab
(F) Ground Floor Slab

Environmental Parameters

Table 6 Environmental Parameters

Date/Time	Indoor Air Temperature		Radiant Temperature		Operative Temperature		Mean monthly Outside Dry-Bulb Temperature	
	°C		°C		°C		°C	
	H1	H2	H1	H2	H1	H2	H1	H2
January	16.70	18.68	16.92	18.97	16.81	18.82	16.81	14.05
February	18.98	21.14	19.18	21.44	19.08	21.29	19.08	16.50
March	23.49	25.33	23.81	25.92	23.65	25.62	23.65	21.94
April	27.07	28.01	28.24	29.31	27.65	28.66	27.65	28.25
May	28.61	29.02	30.11	30.49	29.36	29.75	29.36	31.78
June	29.21	29.44	30.83	31.00	30.02	30.22	30.02	33.18
July	28.28	28.73	29.59	30.06	28.93	29.40	28.93	31.29
August	27.68	28.24	28.77	29.42	28.22	28.83	28.22	29.98
September	27.37	28.06	28.41	29.21	27.89	28.64	27.89	29.30
October	25.65	26.78	26.28	27.62	25.96	27.20	25.96	25.35
November	22.04	24.11	22.31	24.56	22.18	24.34	22.18	19.50
December	17.71	19.79	17.96	20.13	17.83	19.96	17.83	14.76
Run Period	24.42	25.63	25.22	26.53	24.82	26.08	24.69	24.69

Energy Loads

Table 7 Loads

LOADS			
	Properties	**Modern House (H1)**	**Contemporary House (H2)**
Cooling	kWh	16929.97	31494.34
Cooling Per Total Floor Area	kWh/m^2	137.87	148.41
Interior Lighting	kWh	1296.17	3377.45
Lighting Per Total Floor Area	kWh/m^2	10.56	15.92
Other	kWh	-	1564.46
Equipment load Per Total Floor Area	kWh/m^2	-	7.37
Occupancy	Sqft/Person	0.0188	0.0188

Site And Source Energy

Table 8 Site and Source Energy

	Total Energy [kWh]		Energy Per Total Building Area [kWh/m^2]		Energy Per Conditioned Building Area [kWh/m^2]	
	H1	H2	H1	H2	H1	H2

Net Site Energy	18226	36436	128	143	148	172
Net Source Energy	21977	48899	**155**	**192**	**179**	**230**

Table 9 Fanger PMV-PPD Model for H1 and H2

Date/Time	Relative Humidity		Fanger PMV		Fanger PPD	
	H1	H2	H1	H2	H1	H2
January	62.23	54.98	-0.93	-0.88	25.03	27.77
February	61.99	54.43	-0.45	-0.30	10.94	15.62
March	50.25	44.62	0.49	0.67	14.13	22.96
April	39.81	37.55	0.83	0.87	24.54	34.50
May	51.68	49.22	1.42	1.32	45.97	47.49
June	55.31	53.01	1.66	1.52	54.14	52.37
July	63.18	59.45	1.39	1.31	45.59	47.65
August	69.28	64.26	1.22	1.16	38.80	43.39
September	64.81	60.00	1.08	1.06	32.98	40.31
October	59.20	53.84	1.06	1.13	31.01	37.02
November	51.70	45.55	0.17	0.37	8.78	16.63
December	55.56	48.85	-0.74	-0.64	18.62	21.87
Run period	57.09	52.16	0.61	0.64	29.35	34.09

Adaptive Comfort Summary

Table 10 Adaptive comfort summary for H1 and H2

	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]	CEN15251 Category I Acceptability Limits [Hours]	CEN15251 Category II Acceptability Limits [Hours]	CEN15251 Category III Acceptability Limits [Hours]
H1	37928.5	29334.5	33895.5	25470.5	20348.5
H2	52951.5	39053.5	46983.5	31888	19706

As per Adaptive comfort model H2 is performing better in both ASHRAE 90% and 80% acceptability limits as well as in CEN15251 category I and II. Whereas H1 is performing better in CEN15251 category III.

Discomfort Hours

Table 11 Time Not Comfortable Based on Simple ASHRAE 55-2004

	Winter Clothes [hr]	Summer Clothes [hr]	Summer or Winter Clothes [hr]

H1	4630.50	4745.00	4252.50
H2	8465.00	8643.50	7824.50

As per all the models of thermal comfort analysis, discomfort hours in summer clothing were highest in H1 in December (403 hours) and least in March (205 hours). Whereas, the summer clothing discomfort hours were highest in H2 in January (446 hours) and least in March (157 hours). Discomfort hours in winter clothing were highest in H1 in August (403 hours) and least in November (106 hours). Whereas, the winter clothing discomfort hours were highest in H2 in July (446 hours) and least in February (111 hours).
Discomfort hours in all clothing were highest in H1 in January (395 hours) and least in November (41 hours). Whereas, the all-clothing discomfort hours were highest in H2 in June (344 hours) and least in November (41 hours).

Table 12 Discomfort Hours in H1 and H2

Date/Time	Discomfort hrs (summer clothing)		Discomfort hrs (winter clothing)		Discomfort hrs (all clothing)	
	H1	H2	H1	H2	H1	H2
January	403	**446**	395	341	**395**	341
February	362	365	265	**111**	264	90
March	**205**	**157**	230	366	58	99
April	209	254	382	432	207	254
May	317	325	**403**	**446**	317	325
June	334	344	390	432	334	**344**
July	335	330	403	446	335	330
August	342	328	403	446	342	328
September	314	287	390	432	314	287
October	220	212	359	444	**197**	212
November	294	188	**106**	245	41	**41**
December	**403**	438	372	245	372	241
Runtime Period	3737	3674	4096	4386	3175	2893

Internal Gains
As per internal gains data as shown in Table 13 **INTERNAL GAINS GRAPH FOR H1 AND H2 (KWH)** the gains in H2 are higher in every aspect, but if we only look at solar gains the difference is significantly higher, due to the higher WWR.

Table 13 Internal gains graph for H1 and H2 (Kwh)

	General lighting	Occupancy	Solar Gains Exterior Windows	Zone Sensible Heating	Zone Sensible Cooling	Total Latent Load
H1	1296.17	838.51	838.51	49.79	-13185.23	808.77
H2	3377.45	1251.47	**22189.44**	0.03	**-25089.8**	1310.95

CONCLUSION

In terms of Thermal comfort; H1 is performing better than H2 in both the PMV-PPD model, Pierce comfort model. H2 is performing better than H1 in Adaptive comfort model. Looking at the discomfort hours data, H2 has 3572 more hours of discomfort than H1.
In terms of Energy Use, energy use per total building area of H2 (192 kWh/m2) is more than the H1(155 kWh/ m2). Also, the energy use per conditioned building area of H2 (230 kWh/m2) is more than the H1(179 kWh/ m2).

From this simulation we can conclude that the original plans given by Le Corbusier, architect of Chandigarh, were much better in terms of thermal comfort and energy consumption but the newly constructed house is much better performing in visual comfort aspect with bigger and more openings to the outside. Alternatively, with the inclusion of shading devices in the H2 or by decreasing the size of windows towards the south we can achieve better results in terms of thermal comfort as well as energy consumption in H2. Attention should be given towards Window-to-wall ratio of H1 and H2(8.92% and 26.24% respectively) as that being the major component affecting the gains from the building envelope. This study can further be implemented to conduct similar analysis on residences designed by Pierre Jeanneret and Le Corbusier.
This paper is a part of a broader study being carried out to establish the relationship of building regulations and policies with occupant comfort and energy use.

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12. GOI. CLIMATE OF SMART CITY - CHANDIGARH UNION TERRITORY : CHANDIGARH The climate of the district is humid subtropical characterized by a seasonal rhythm : very hot » Thunderstorm sometimes occur during February to during April to June and in the months of Augu. 30.