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Effect of using greenhouses instead of balconies on energy conservation in buildings.

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Abstract

Growing energy demands with an increasing population have reiterated the importance of energy conservation. Buildings share a large portion of energy use worldwide. Energy efficient building technologies help to maximize solar heat gain in winter, minimize it in summer and optimize energy requirements in buildings. In present paper, effect of existing balconies in several storey buildings on indoor heat losses in the cold winter through infiltration and thermal bridges will be analyzed experimentally in a real existing case study in Tehran, and then the results will be compared with the same building section simulated in the software considering separated greenhouses instead of those balconies and analyzing the effect of using this strategy on energy saving in the building during the cold winter climate in Tehran. The results shows the southern greenhouses will play a significant role, not only in preventing energy losses but also a large amount of energy conservation in building, and the other faced greenhouses may effect on energy saving not as much as the southern ones, but the results of computational analysis will prove that they can be very useful for reducing energy losses through those unprotected balconies. Of course, these greenhouses could help to lower indoor air temperature during summer by natural ventilation through their complete sliding surfaces and converting them to open spaces balconies. Combined effect of well-considered energy efficient building technologies is thus useful for energy conservation and also summer cooling in buildings.

Key words

Energy conservation, Greenhouse, Energy losses, Conduction, Heat transfer, Simulation, Balcony

I. INTRODUCTION

A. Problem description

Energy consumption can be divided into four main areas: agricultural, industrial, transportation, and building sectors. The residential and commercial building sector is the largest energy consumer [1]. In the United States, the energy used to construct and operate buildings constitutes 48% of the total energy use. In most developed countries, regulations concerning the required energy efficiency for new construction have become stricter. The European Union also regulates the energy efficiency of buildings by directives and incentives. There are several studies dealing with the energy efficiency of the different components of buildings such as the cladding, electrical, structural and mechanical systems [2-4]. The state of energy efficiency of existing buildings should be under investigation and the results could show a notable improvement in the buildings energy use [5], most of the energy is used for heating and cooling; therefore, regulations are targeting the improvement of heat insulation systems. Most of this energy is used for heating in the cold climate zone, for cooling in the tropical territories, and for both heating and cooling in the temperate zone. Insulation efficiency depends on how long the energy can be kept inside or outside the building. There are optimization methods for calculating the minimal cost of buildings, initial cost of heat insulation materials, and the cost of energy used for heating and cooling [6,7] . Investment cost of insulation is determined by the present market price; however, the price of energy cannot be predicted easily for the lifetime of a building. Rising energy prices and strict building regulations force the construction of buildings with better heat insulation systems, and minimize the thermal bridges both in the walls and the roofs. The implementation of the Directive 2002/91/EC in the form of national laws by each member state, gradually leads to the need to adopt advanced standards, techniques and technologies while designing and constructing new buildings, but also in applying energy renovation measures in existing ones, in order to comply with the updated energy efficiency requirements [8,9]. The features of the urban built environment in many European countries impose limitations, or at least restrictions, on implementing other advanced renovation measures like the use of passive or active solar systems, passive cooling techniques, etc. This is mostly due to factors like the overshadowing of buildings in winter, the unfavorable orientation and the architectural typology of buildings' façades. Even in cases where such measures can be implemented, it is still rather impossible to achieve a satisfactory degree of energy efficiency, as long as the buildings present high thermal losses through their external envelope. Although in most of developed countries such rules affect in energy use in buildings but still there are some problems in setting up and implementing these kinds of rules for preventing energy losses and achievement to gain much renewable energies such as solar gains and wind energy in most countries such as Iran that are developing these years. In that sense, the less glamorous but still most effective measures, such as the buildings' envelope thermal insulation, removing thermal bridges and the heating systems' upgrading remain prerequisites for a realistic approach towards the improvement of the building's energy efficiency.

The heat insulation system with higher thermal resistance (R value) usually requires more space in the wall, resulting in the need for more material and therefore, higher costs. Ultimately these factors create a need for the research and development of more effective insulation materials and systems. More efficient insulation systems have a higher thermal resistance at a given thickness and also reducing thermal bridging effect and thus occupy less space in the wall. Also for the existing buildings with different typology, we could consider some other solutions to reduce the energy losses of the building façade, through implementing proper insulation, reducing the thermal bridging effect through designing methods and some other strategies that could be done with very low cost and time expending.

The overall objective of this study is the development of a case study building façade, not with implementing any insulation yet but just with applying a simple alteration in the building envelope and the way we could use it. The investigation includes the analysis of applying these changes in three possible conditions and also the calculations that will lead us to the results.

B. Theory

Traditional building balconies in Iran and mostly in Tehran were built with wide area of glass using for constructing windows and doors. These building types can be found in every street and covers in high numerous of old built construction with a longevity about 30 to 40 years. Although the traditional buildings in Iran are famous in the world of architecture because of well-built and designs, but these building types were became popular in late century. If we concentrate to these constructions from the point of view of an energy audit, we could easily found out to what extent these non-protected envelopes will cause a great amount of energy losses through those wide and clear glasses and walls with no insulation systems. Heat transfer occurs in three different ways: conduction, convection and radiation [3], Heat conduction is the transfer of heat due to molecular collisions. In solid materials, the molecules are nearly in contact with each other. This close proximity results in an easy transfer of thermal energy. To achieve higher thermal resistance, it is better to have increased spacing between molecules such as in the gaseous phase. With gas, heat transfer by conduction depends on the velocity of the molecules, which in turn is determined by the mass and temperature of the molecules. Heavier gas molecules are known to have significantly slower velocities than the molecules of a gas with a very low molecular mass. Therefore, a heavier gas with slower velocities has a lower thermal conductivity than that of a lighter gas. Convection is the process whereby heat is transferred by the mass movement of molecules from one place to another. Radiation is heat transfer involving the change in energy form from internal energy at the source to electromagnetic energy for transmission then back to internal energy at the receiver. These kinds of facades of our case study will have a great amount of energy losses through all these directions. If we consider these energy losses in a street constructed with such kinds of houses and then in an urban area and lastly in the whole city, there will be a very big amount of energy that has great costs for the government to produce, manage and transfer to the urban network and houses, and also for the users to pay its cost, and finally the amount of Co2 emission to the air, that has made an unsolvable air pollution for Tehran these days, all will demonstrate the importance of solving such these problems and help energy conservation in building sector. To prevent these energy losses without any basic changes and cause costs and construction problems for inhabitants, there are some ways that one of them is to apply thermal insulation from external side of the walls. Although in theory it seems this way is the only useful job to be done, but how ever in actual construction practices it has some implementing difficulties and has financial costs that maybe it's the main reason that the landlords hesitate to accomplish any of these changes in their houses [9]. So in the present paper we will discuss about another strategy to reduce these heat losses through changing these balconies to some kinds of greenhouses by implementing a simple glass in front of the balconies in this level of research, so that we could just discuss the results of the greenhouse only, and not to use any other materials such as UPVC windows or any other insulations to affect our calculation and analysis. Heat and energy in general, because of molecular properties, always desire to move through a warmer place to the colder place through the all three thermal transmittance ways that we mentioned before [10], and these occurs in actual example through air change of the space, transmission through the cortexes of the space and the radiation of different components of the surrounded space. In order to reduce thermal transmittance and equally heat losses, we should effect on these actions in some ways and control the amount of them. So the purpose of this paper is to investigate how it could be useful to reduce the temperature variation between inside and outside of the space and of course reduce this effective variation on both inner and outer side of the space cortexes.

Fig. 1. The photo of the case study building showing the position of its balcony

II. METHODOLOGY

This study is a research paper was built on literature review, field study and experimental solutions. In order to conduct this study, a typical three-storey building with typical plans and a flat roof was chosen as a representative urban residential building type. Each storey consists of one apartment with a total area of 112 m^2 that is about 8 m width and 14 lengths (Fig. 1). Each storey has a southern balcony with about 1.5 m width and 8 m length that make a floor area about 12 m^2 for them. The building is located in the city of Tehran, in northern half of Iran. The main climatic data for this area, which are summarized in Table I. could help to better understand the environment situation. Because in this research we just want to concentrate on the effect of balconies and its amount of heat losses, two dimensional heat transfer is needed and because all the three storey has the same construction detail, we considered a repeated wall section from façade and balcony to be sure this will cover all probable situations and sections (fig. 2). For calculations the THERM software has been used according to the numerical data's and conditions of the National building regulations of Iran for energy conservation in buildings. In this investigation, effect of other elements hasn't been considered so that the results will show only the complemented strategy that we need to figure out, although it could be developed later through examine other strategies and also the combined ones, and the complexity of various envelope details further exacerbates the inaccuracy of using simple methods and requires 3D analysis to truly account for all the heat flow paths.

Three different scenarios are examined and the U-values and also thermal bridging effect and total heat transmittance will be calculated, this vertical section of the façade is symmetric to Y direction and for X direction, for left side, we considered whole part of balcony and for the right side, 0.7 m long of the storey floor where concerned for calculations. (This length were obtained after several calculations with different lengths that the results were the same and constant for more than this length in thermal transmittance) (Fig. 2.). The boundary condition temperature and also film coefficient according to National building regulation of Iran are as in Table II. The first scenario (A) represents typical balcony details as our case study construction in Iran buildings. The second scenario (B) represents, the situation that we add a glass construction in front of just the middle storey balcony as a greenhouse in cold winters but not also for the top and bottom storey in this scenario, the shape and details of installation are not part of this study so we consider it as the scenario A, the difference is as we change the balcony to a close space as a buffer, so we don't apply any action to keep that cold or warm but because it will react as an interface space between the warm climate inside and the cold climate outside, so it will have temperature not as cold as outside neither as warm as inside. The temperature of this space were calculated after the software analysis for scenario (A) and calculating the U-values for cortexes that face outside and inside and as in

$$\tau = \frac{\sum U_e.A_e}{\sum U_e.A_e + \sum U_i.A_i} \tag{1}$$

Where above of the fraction is sum total of the U-value multiplication to the area of each elements that face to the outside, divided on to sum total of last number with sum total of U-value multiplication to the area of each elements that face to the inside that will results the reduction factor of this space. After wards, as in

$$\tau = \frac{T_i - T_b}{T_i - T_e} \tag{2}$$

TABLE I. Climatic data for Tehran

Month	Mean daily ambient temperature (◦C)			Mean relative humidity (%)	Daily Solar Radiation (Wh/m2)	Heating degree days (18 8C)
	Minimum	*Mean*	*Maximum*			
January	-4.9	2	10.9	59	4274	481.3
February	-4.8	4.3	11.6	50	5257	369.5
March	-1.6	9.7	17.3	39	5732	244.0
April	3	15.7	25.6	31	7097	88.8
May	9.3	21.8	29	25	8258	14.3
June	15	27	34.4	19	9918	0.6
July	19.5	30.5	38.5	19	9631	0.0
August	18	29	35.7	19.5	9339	0.0
September	17.9	24.5	34.3	20.5	8326	2.0
October	10.6	17.7	27.7	28.5	6726	53.1
November	0.6	10.5	18.4	39.5	5060	211.8
December	-1.3	4.5	12.3	55.5	4086	402.0
Total					83704	1867.4

Where T_i is inside temperature, T_e is outside temperature and T_b is the buffer temperature, according to the National building regulation of Iran instructions, we could obtain the temperature of this space and then this temperature will considered as the boundary condition temperature in the software to calculate the average U-values of the envelope. The third scenario (C) represents the case that all of the three storey balconies were considered as buffer spaces and equipped with the glass construction in front of the balcony. In this case again the reduction factor will be calculated with new situation for the middle storey. Because the above and bottom side of the balcony are also buffer space so the floor and the ceiling of the middle storey buffer were not considered in the calculations as

TABLE II. Boundary conditions and film coefficient values for different heat transfer paths

Boundary Conditions	Temperature	Film Coefficient *Heat transfer direction*					
							
Inside	$20^{\circ C}$	111.11		9.09			
Outside	$0^{\circ C}$	20		16.66			
Buffer(Scenario B)	$6^{\circ C}$	*Ext*	*Int*	*Ext*	*Int*	*Ext*	*Int*
		20	11.11	9.09	9.09	20	5.58
Buffer(Scenario C)	$9^{\circ C}$	5.88	5.88	9.09	9.09		

TABLE III. MATEIALS PEROPERTIES CONSIDERED FOR THE CALCULATION

Materials	Conductivity(λ) w/m.k	Emissivity
Concrete	2.3	0.9
Birck Wall	1	0.9
Glass	1	0.84
Frame Frofile	50	0.6

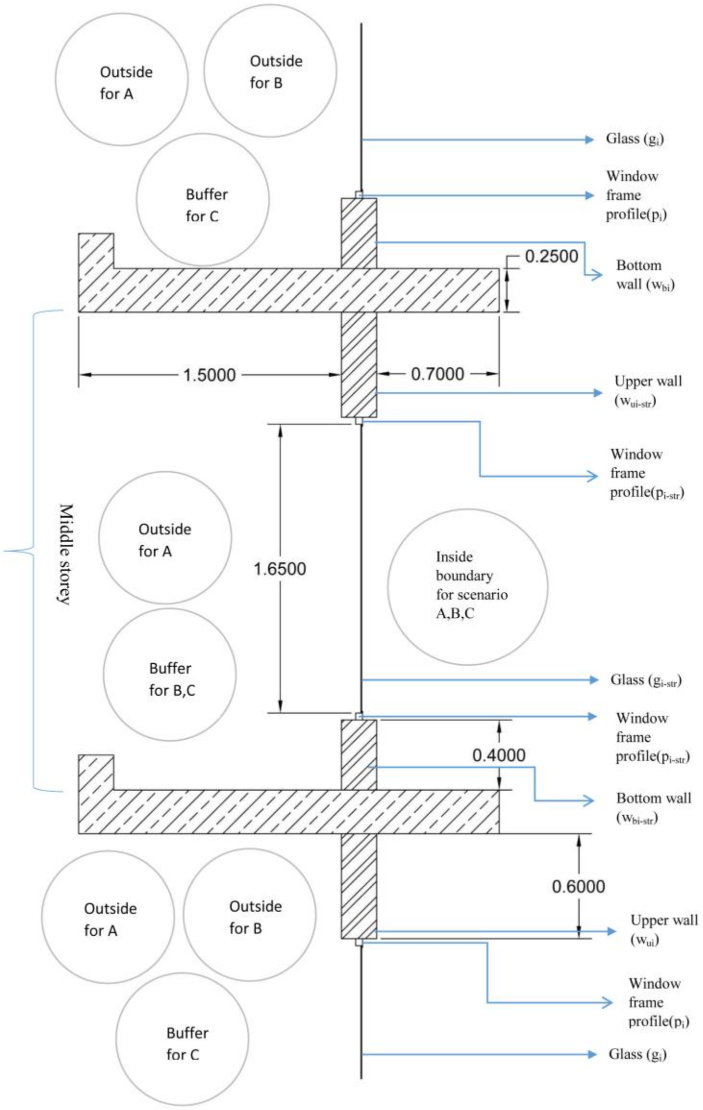

Fig. 2. The symmetric section of the external envelope, showing boundary conitions, elements name and size (scale, 1:20)

in

$$\tau = \frac{\sum Ue.Ae}{\sum Ue.Ae + \sum Ui.Ai} \quad (1)$$

And next we could calculate the new temperature for the buffer space that will concerned as the temperature of all buffer spaces when resulting the U-values in scenario C. All the calculations were considered for a width slice about 1-m-long and the area in calculation U-values is as this in order to have unique amounts of numbers and it could be developed to what extent that is needed next.

After all the scenarios were simulated in the software and the average U-values and also separated elements U-values were resulted, then two important factors were calculated. The first that plays a significant role in amount of thermal losses is thermal bridging of the section, this factor were calculated as in

$$U_{Avg\,(A)} . A_{total} = \sum U_{wbi} . A_{wbi} + \sum U_{wui} . A_{wui} + \sum U_{gi} . A_{gi} + \sum U_{pi} . A_{pi} + 2\Psi \quad (3)$$

, (the values to calculate via this formula are shown in table IV.) for all scenarios to show this action how could affect on reducing thermal bridging and thermal losses of the building through this simple applied strategy. And finally the P factor for resulting the thermal power were calculated as in

$$P_{str(A)} = U_{Avg(A)} . A_{str} \quad (4)$$

($P_{str(A)}$ means thermal power for the middle storey in scenario A), ($U_{Avg(A)}$ were calculated from THERM), ($A_{str} = \frac{A_{total}}{2}$)

Where A_{str} is the total area of the envelope elements with 1-m-width divided by 2 for resulting the elements area of the

TABLE IV. U-Value For 1-M-Long Of The Envelope For All examined Methodologies

Scenario	U-Value For 1-m-Width Of The Setion (W/m^2.K)				
	Average U-Value	Separate Parts U-Value			
		W_{bi} A_t=0.8m^2	W_{ui} A_t=1.2m^2	G_i A_t=3.4m^2	P_i A_t=0.2m^2
A	5.26	2.67	2.68	5.74	5.9
B	4.14	2.16	2.17	4.44	4.65
C	2.33	1.27	1.28	2.46	2.68

middle storey. After this section, for calculating the P changes in scenario B we will use the formula as in

$$\Delta P_{str(B)} = \sum U_{wb} . A_{wbi} + \sum U_{wu} . A_{wui} + \sum U_{gi} . A_{gi} + \sum p_i . A + 2\Psi - P_{str\,(A)} \quad (5)$$

And for all the scenarios to emphasis how this approach could be helpful identically for reducing the totally heat losses of the building.

The results of the calculations will introduce and discuss in separated tables but to determine the results, the calculation process will be done for one scenario and other will be in the same way. The specification of the materials properties that were considered for the section construction details are listed in the Table III.

III. Results

After calculating the results from the software and also the given formulas, the required values for comparison, U-values, thermal bridging and thermal power were calculated separately. The procedure of the calculations for scenario A and also the way of obtaining the temperature for the buffer space for scenario B are the followings.

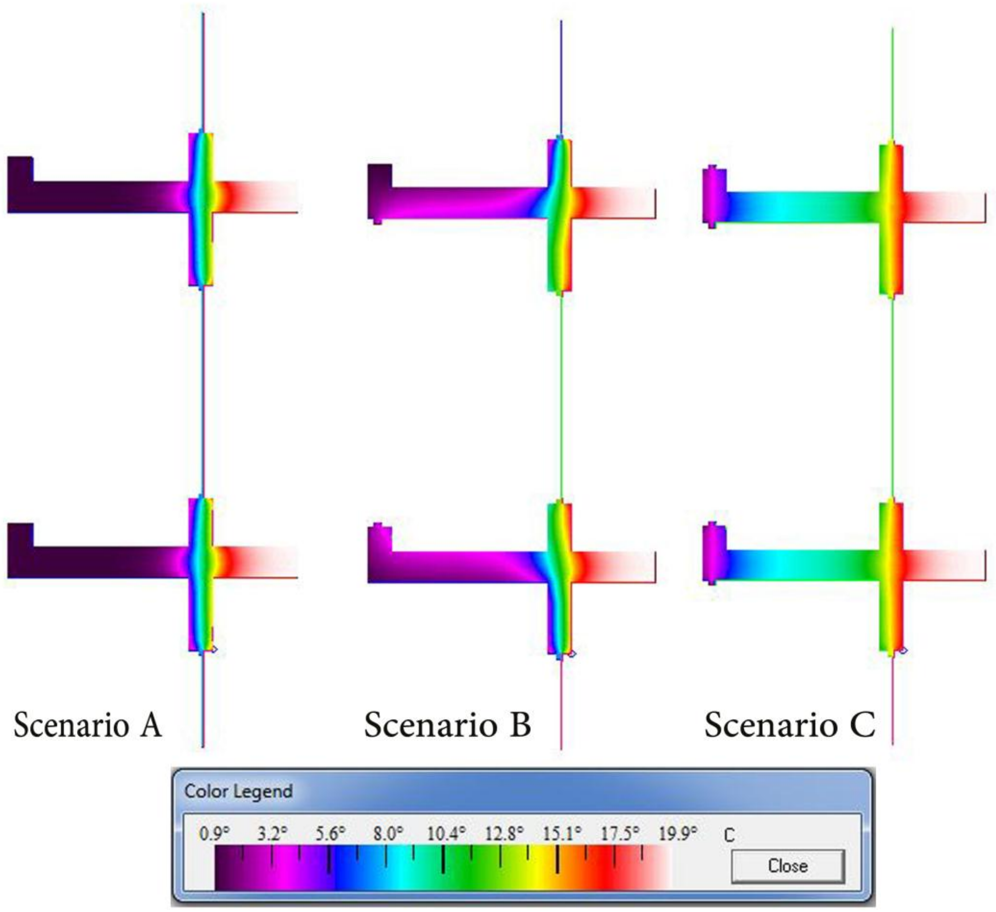

Fig. 3. The sections shows the temprature colorized heat flow for three scenarios calculated using THERM.

$U_{Avg\,(A)} . A_{total} = \sum U_{wbi} . A_{wbi} + \sum U_{wui} . A_{wui} + \sum U_{gi} . A_{gi} + \sum U_{pi} . A_{pi} + 2\Psi$

$5.26*5.6=2.67*0.8+2.68*1.2+5.74*3.4+5.9*0.2+2\Psi$

$\Psi=1.72$ W/m.K

$P_{str(A)} = U_{Avg(A)} . A_{str}$ $\quad P_{str(A)} = 5.26*2.8=14.73$ [W]

$$\tau = \frac{\sum Ue.Ae}{\sum Ue.Ae + \sum Ui.Ai}$$

$$\tau = \frac{\sum U_{gi\,str} . A_{gi\,str} + U_{pi\,str} . A_{pi\,str} + U_{Concrete\,floor\,str} . A_{concrete\,floor\,str} + U_{Concrete\,ceiling\,str} . A_{concrete\,ceiling\,str}}{\sum U_{gi} . A_{gi} + U_{pi} . A_{pi} + U_{Concrete\,floor} . A_{concrete\,floor} + U_{Concrete\,ceiling} . A_{concrete\,ceiling} + \sum U_{Wstr} . A_{Wstr} + U_{gi\,str} . A_{gi\,str}}$$

$$\tau = \frac{23.4}{23.4+9.38} = \frac{23.4}{32.8} \longrightarrow \tau = 0.71$$

$$\tau = \frac{T_i - T_b}{T_i - T_e} \quad 0.71 = \frac{20 - Tb}{20 - 0} \longrightarrow$$ Tb = 6 °c for buffer space in scenario B

The overall heat transfer U factors for 1-m-width of the section measures the rate of heat transfer through a building envelope over a given area. Table IV. shows the experimental results for the calculated U-values in the scenarios using THERM. Where the top, bottom and right ends of the section considered as adiabatic boundaries to approximate the heat flow through the considered part of the façade. To allow for the comparison of the results the thermal bridging and thermal power are calculated and all are shown in fig. 4. For better understanding the effect of this action for scenarios and how much it could be effective.

The results show a very good reduction of thermal bridging after applying the recommended actions. In scenario A that is the same as the existing building treatment, the thermal bridge number is 1.72 W/m.k that it seems to be much for 1-m-width of a building section. In scenario B after applying the glass construction the thermal bridge will reduce to a number of 1.5 W/m.k it means this effect is still exist through the top and bottom cortexes of the middle storey. The notable point is that in scenario C this number will consequently break down and shows us 0.85 W/m.k for the thermal bridge amount. It means as we apply this strategy for all 3 storey, the heat losses of the envelope will reduce by reducing the thermal bridge effect. This experiment shows although no insulation were applied but how much this measure could be affecting the thermal transmittance of the building and reduce the heat losses during

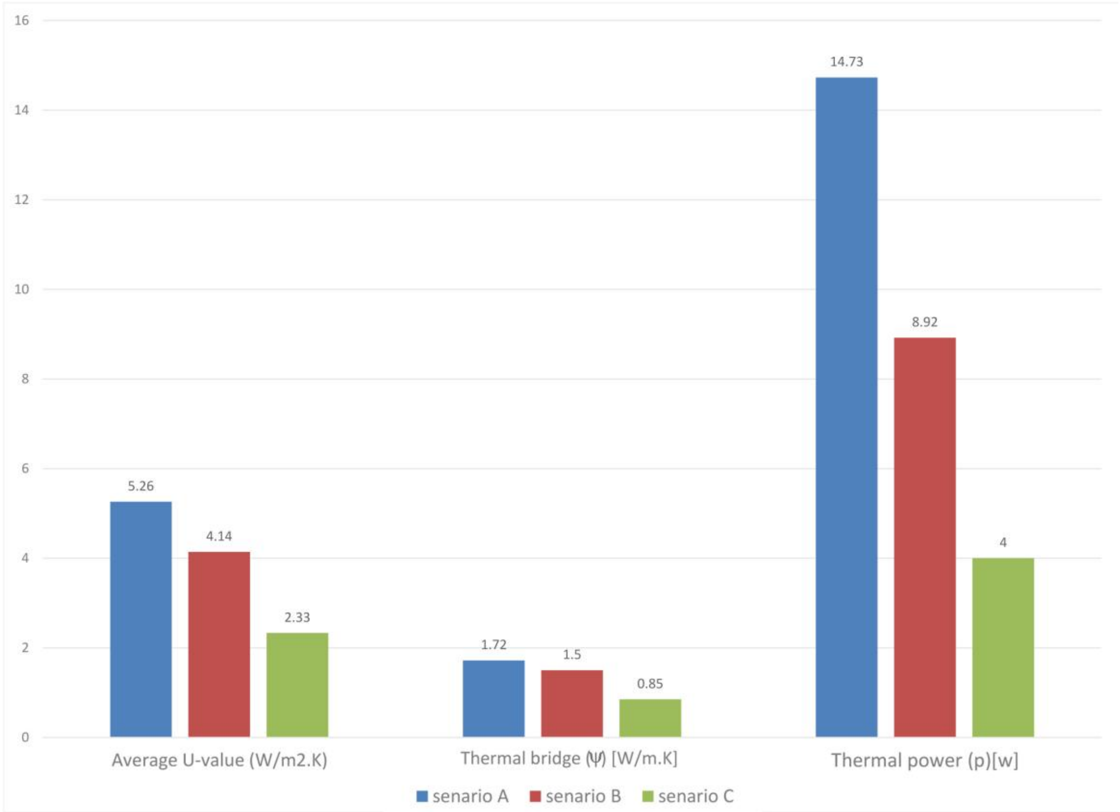

Fig. 4. Calculated results for 3 experimental scenarios that shows the effect of applied actin via variation of values.

the cold winter days.

Another measure that proves the basic hypothesis more than before is the thermal power as it was calculated for scenario B as follows:

$\Delta P_{str(B)} = \sum U_{wbi} . A_{wbi} + \sum U_{wui} . A_{wui} + \sum U_{gi} . A_{gi} + \sum p_i . A + 2\Psi - P_{str\,(A)}$

$\Delta P_{str(B)}$ = 2.16*0.8+2.17*1.2+4.44*3.4+4.65*0.2+2Ψ-14.73

$\Delta P_{str(B)}$ = 8.92 [W]

Through the past discussed formulas and the results as in fig. 3. That are the same were expected, ingeminate the positive growth in energy conservation because of this applied strategy.

The amount of the P for the scenario A is 14.73 W but after applying the glass construction for the middle storey it reduced to number 8.92 W for scenario B, and lastly in scenario C, it will show a great reduction in comparison with scenario A by the number 4 W, the thermal power that is needed to heat this concerned area of the envelope. Fig. 3. also shows the color section of the scenarios and the heat flow path via colorized temperature using THERM.

IV. DISCUSSION

As the results are shown in fig. 4. a notable amount of variation is considerable in the values of all factors. Applying the recommended strategy for just the middle storey will cause a reduction of thermal power about 40 % and it will be a greater amount when applying the glass construction for all balconies of the building that is about 73% , fig. 3. also shows the colorized heat flow for three scenarios calculated using THERM. The reason for this reduction is decreasing the surfaces conduction and also reducing thermal bridge effect via increasing the outside temperature of the external envelope so the molecular movements will decrease [10] and that will cause reducing the U-values of the elements and also the average U-value so these will result also a higher thermal resistance as in

$$\frac{1}{U\,total} = R\,total\ (m2.K/W) \qquad (6)$$

This investigation were considered without direct solar energy effect, for northern facades or which are in shadow range of neighborhoods, so that we could have the results in the worst situations, to examine just the reduction of thermal bridges. If the direct solar energy will be added to these amounts, of course the temperature of the buffer space will be higher than this according to the energy that the surfaces will absorb. In that case not only the thermal bridge effect and thermal losses will disappear, but also we could use the warm air accumulated in the greenhouse during the day for heating inside the building. Also through thermal masses of the greenhouse surfaces, an amount of heat energy will be stored and during the night through radiation and convection effect, the heat of the surfaces will transfer to the colder side of the wall that is inside of the building[10].

At the next level of optimization of the building according to landlord demands, only by adding a thin insulation layer approximately 5 cm thickness, the thermal bridge effect will completely disappear and of course the treatment of the building because of direct solar gain will be different and it is because of thermal inertia of the surfaces will reduce and this process should be calculated more exactly by using other 3D analyzing software's such as Energyplus to have more accurate and treatable results.

V. Conclusion

This study was intended to determine the effect of using greenhouse instead of balcony on heat transfer through conduction effect by measuring U-values and thermal bridges of three experimental scenarios of the case study building in Tehran. The following results can be summarized:

-Surfaces that have temperature variation inside and outside tend to transfer heat from warmer side to the colder side through conduction, radiation and convection, that for solid masses the portion of conduction is more impressive [10], and the convection amount depends on the air change rate of the space influencing by natural ventilation or because of slits at the joist of different applied elements. So in order to reduce this amount of heat losses one useful measure is to use construction materials with low conductivity for new buildings and try to reduce the temperature variation between the two sides of the surfaces.

-Changing the old balcony to greenhouse via applying a simple glass construction in front of the balcony will result reduction of the temperature variation between two sides of the external envelope of the building, and subsequently the reduction of conduction, thermal bridges and finally the total heat losses of the building. If this measure will be applied at the southern façade of a building it will result more direct heat gains in addition to reduction of thermal losses.

-This approach proved effective reducing heat transfer through conduction by decreasing surface both sides temperature variation. Basic financial calculations and practical measures also could establish this strategy could be applied for most of building types in Tehran with different usages without any difficulties in cost and construction details in comparison with other strategies, while the actual results will worth more and will have a significant portion in the part of energy cost, energy conservation and accordingly the reduction of Co_2 emission that will be much beneficial for dealing with current air pollution in the worldwide environment.

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