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Integración BIM de sistemas solares térmicos en diseño inicial de viviendas

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Abstract

This paper sets a methodology to integrate solar thermal systems in BIM-software for the early architectural design of single houses in Concepción, Chile, using parametric families, programming in Dynamo, energy calculation with LadyBug and piping design in MEP. The results obtained allowed to select products, insert and adapts automatically the parametric designs into the model, as well as to identify changes in the type and number of solar components when the solar orientation of the house is modified. It can be applied to more products, different geographic locations and designs of houses or buildings with a similar methodology.

Key words: Solar Thermal System, Parametric analysis, architectural integration, BIM.

Resumen

Este trabajo desarrolla una metodología para integrar Sistemas Solares Térmicos (SST) en software de diseño BIM durante etapas iniciales del diseño arquitectónico de viviendas unifamiliares en la ciudad de Concepción, Chile; mediante el uso de familias paramétricas, programación algorítmica en Dynamo, análisis medioambiental con Ladybug y diseño de sistema de tuberías en MEP. Obteniendo como resultado un método de diseño integrado que permite seleccionar productos solares y adaptarlos automáticamente en el diseño de la vivienda, identificando el tipo y cantidad de componentes a utilizar en función al ángulo de inclinación del techo y orientación; existiendo la posibilidad de aplicarlo con más productos, diferentes ubicaciones geográficas y diseños de viviendas o edificios con una metodología similar.

Palabras clave: Sistema Solar Térmico, Análisis Paramétrico, Integración Arquitectónica, BIM.

Introduction

Solar collection technologies integrated into buildings help to reduce fuel consumptions and greenhouse gas emissions significantly (Yan et al., 2013), but it is required to be incorporated in early stages of building design. The "IEA SHC Task 41 document: Solar energy and Architecture", establishes that the solar energy systems do not have as much demand to be integrated into the buildings for the following reasons: economic factors associated with the investment and maintenance costs, lack of technical knowledge from architects and manufacturers, and control of the architectural aesthetic in the envelope of the building. This last factors derived from the lack of tools that can evaluate and illustrate the influence of several applications of solar energy in a beginning of building design that allows doing changes of the project (Wall, Windeleff, & Lien, 2008).

The methods that describe and recommend implementing solar thermal systems (STS), photovoltaic and hybrid in buildings, lack tasks, like to identify surfaces with higher solar potential related to morphology, function and structure of a building in the early stages of design; to match the collection of solar radiation with the performance of each technology to meet needs as domestic hot water, heating and electricity, as well to develop the detail of the installation in the building design and architectural visualization of the system (Horvat & Dubois, 2012).

To address the integration of performance analysis in the building design process, some studies have been done with parametric tools (Rahmani et al., 2015) (Jakubiec & Reinhart, 2011). These studies try to enable designers to explore various formal options and access energy assessment quickly. The common goal of all of these studies is to create a programming to relate the geometry of the building in the early design phase with performance analysis. Most of these tools are created with Rhinoceros® (Rhino), a 3D modeling program, with visual programming editor, Grasshopper®, which facilitates parametric design, linked to energy calculation engines. Nevertheless, these platforms

do not have access to all building elements and workflow available in BIM (Building Information Modeling) systems, like Revit, Archicad and Nemetschek, that are increasingly used in the construction industry to develop the design and manage design delivery process (Rahmani et al., 2015).

During the design process, the performance of a scheme might be optimized by a sequence of analysis and feedback. BIM consolidates this iteration, since the intelligent model serves as a common, continuously up-to date database that is steadily refined until the desired objectives are met (Lobos, Wandersleben, & Castillo, 2014) (Liu et al., 2015).

The ideal and automated integration of multi-criteria design evaluation with BIM is not fully implemented yet. Instead of automatically generating a Building Energy Model (BEM model), manually re-entering of architectural and technical information into a static calculation or dynamic simulation software is common practice: a highly inefficient working method, prone to errors (Senave & Boeykens, 2015).

By such reason, this article sets a methodology to integrate solar systems in a BIM-software, with the example of a real-estate house in Concepción, Chile. Through an experimental research to identify and characterize solar thermal systems (STS) available in the zone and typical single-family houses of real-estate complexes, to define their characteristics and linked them to the BIM software using an algorithmic programming with Dynamo, piping layout with MEP, energy calculation with LadyBug, as well as economic assessment and architectural visualization.

The study obtained an integrated design method that allowed to select products, insert and adapts automatically into the parametric building model. And also, to verify their adaptability to each design of houses. Besides, the parametric analysis allowed identifying changes in the type and number of solar components when the solar orientation of the house is modified

This integration of the BIM concept into the design stage can and be used to select the best green building designs and reduce the need for later design modifications that require extra time and cost. Efforts to prevent adverse environmental impacts and to minimize energy costs are beginning to show beneficial effects in terms of more efficient and sustainable building designs, improved building performance, and minimization of environmental risks (Shoubi et al. 2015)

Methods

First, a review of solar thermal systems (STS) most used in the zone was carried out, to define the shape and technical features of products proper to be integrated into roofs of single-family houses in Concepcion. Secondly, a selection of two cases of real-estate models was done, that have different roof inclination (40° and 27°) and built surface, but a similar amount of rooms: 3 bedrooms, 2 bathrooms, family room, kitchen and living-dining room. Third, it was applied the parametric design of all components of STS in the digital model of the houses created in Revit software. Algorithmic programming generated with language Dynamo and environmental analysis through Ladybug enabled the calculation of the panels and tanks most suitable to the orientation and roof configuration of each house. Linked to an Excel table to determine the collection solar area and the accumulator capacity necessary to supply the demand of domestic hot water, according to national law 20.365 that provide a state subsidy for these installations.

The procedure carried out allowed to select products, insert and adapts automatically the parametric designs into the model. And also, to integrate them into a piping layout with MEP utilities of Revit software, optimizing the routing and connections between the fittings and domestic equipment; in order to verify their adaptability to each housing design.

Characterization of solar thermal systems (STS) and housing models

It was determined that the STS of forced type is the most suitable for architectural integration of houses, due it allows inserting solar collector on the roof independently to the other elements of the system. These systems have collectors of different types and dimensions. The most commonly used are plane collectors, which have 2.0 m² or 2.4 m² of the catchment area, and the Heat pipe, which an area of catchment between 2.6 m² and 4.4 m² (Table 1). Both of them can have accumulators of DHW (Domestic Hot Water) type glazed with coil and capacities between 200 l and 500 l. This information allowed creating in Revit software the parametric family of each element with the geometry and technological features for the calculation of the STS, with the possibility to generate various options of design in function to the demand of ACS and features of the housing.

Technical specifications		Heat pipe collectors			Plane collectors	
Characteristics	Unit	Zelios VDF 15	Zelios VDF 20	ILHC - 5830	Wunder CLS 2510	Wunder CLS 2108
Amount heat pipe		15	20	30		
Weight	Kg	51	68	92.6	44	37.2
Size	mm	1380*1910*178	1840*1910*178	1894*2310*135	1988*1218*90	1988*1041*90
Working pressure	bar	6	6		10	10
Liquid content	l	4.3	5.7			
Absorption	%	95	95		97	97
Emissivity	%	5	5		3	3
Total surface	m²	2.63	3.51	4.37	2.42	2.07
Opening surface	m²	1.58	2.12		2.24	1.92
Absorption surface	m²	1.51	2.01	2.4	2.23	1.9
h_o		0.816*	0.821*			
K_1 w/(m²k)		2.735*	2.824*	2.46	3.514	3.514
K_2 w/(m²k²)		0.0074*	0.0047*	0.0007	0.008	0.008
Stagnation temperature	°C	206	206	250	211	211
Glass material				Borosilicato 3.3	Tempered glass	Tempered glass
Transmittance glass	%				91	91
Thickness glass	mm				4	4
Insulating					Mineral wool	Mineral wool
Thermal conductivity	w(mk)				0.037	0.037
Optical performance	%			72.5	76.3	76.3

To identify current housing models built in the city of Concepcion, it is taken as reference the county archive of building projects from 2006, where are identified the bigger real estate complexes with 2139 houses built. This coverage provides a statistically 95% confidence interval with respect to all homes built during the period, thus providing an accurate representation of the current residential construction (Zalamea & García, 2014).

The nine-complex real estate reviewed contain 33 models different from single family houses, detached or semi-detached. The five types of houses that present greater number of units according to the total sample, shows a number of houses between 110 to 339 units (Figure 1).

Figure 1. Amount of single family houses built in the five largest complexes in central commune of Concepción. Source: Zalamea & Garcia (2014).
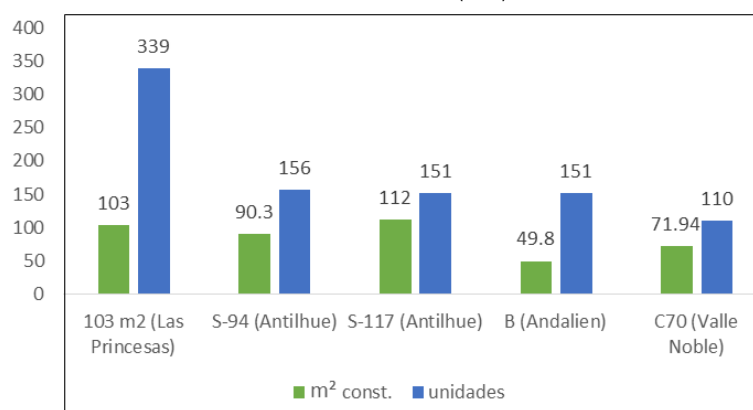
Based on this data, the two models with a greater number of units built the last decade in the central commune of Concepción were selected: a house of 103 m² located in "Las Princesas" complex, and a house belonging to the complex Antilhue (S-94). The selected models are common designs and allows to have detailed building information: type of roof, roof inclination, construction area, and other parameters specified in Table 2.

Table 2. Characteristics of the two housing type. Source: the author.

Characteristics	Unit	Type A	Type B
Name		House S-94	House 103 m²
Complex		Antilhue	Las Princesas
Built Surface on the first floor	m²	51.82	60.53
Total surface	m²	90.25	103
Number of Floors		2	2
Horizontal roof surface	m²	69.21	77.74
Inclined roof surface	m²	94.61	91.76
Amount of Wings		4	6
Surface of biggest roof wing	m²	52.96	43.78
Slope of biggest roof wing	degree	40	26.71
Slope of second biggest roof wing	degree	30.93	22.43
Number of Rooms	unit	3	3
Number of Bathrooms	unit	2	2

The roofs of the selected houses have an inclination of 40° and 26. 71° (Figure 2), which coincides with the common slopes of approximately 1,000 cases studied by Zalamea and Garcia (2014) of a total of 2139 units (47% of the sample). Both cases present different built surface and layout, however, they have the same amount of rooms: 3 bedrooms, 2 bathrooms, family room, kitchen and living-dining room. This condition allows designing the STS with a demand for domestic hot water equal to two cases, with opportunities to explore variations on the system by the differences in roof slope and house orientation.

Figure 2. View of single family house type A (right) and type B (left). Source: the author.

BIM – Parametric families

The representation of the Solar Thermal System (STS) like parametric families include a piping system on Revit MEP by placing mechanical components in the house model, assigning them to a supply or return course. Subsequently, with the use of design tools it can determine the best routing for the pipes that connect the system components.
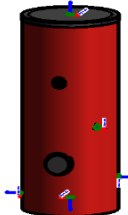
The products identified compound each family associated with the category of mechanical equipment. This category includes different types of components, each one has a graphic representation associated and an identical set of data, called family parameters. The table 3 shows the family parameters to be applied in the process of STS design, with properties of each one, to select which best suits to the requirements of the house.

Link the STS in the parametric design of a house

The parametric family of STS is placed in the house design made in Revit (case of study A) to review its integration, establishing geometric relationships between components. This way enhances the possibility of examining variants without the need to do all representation work again.

The use of parametric families of each of its components, especially the roof, allows it to control the location of entities in the model, and to obtain data of geometry and orientation necessary for sizing and integration of the STS.

Table 3. Parameters of BIM families. Source: the author.

Category	Family	Type	Model	Dimensions	External material	MEP system	3D model
Mechanical equipment	Solar Collector	Heat Pipe - 01	Zelios VDF-15	1380*1910*178	Glass pipe/Aluminun frame	Hydronic System	
		Heat Pipe - 02	Zelios VDF-20	1840*1910*178	Glass pipe/Aluminun frame		
		Heat Pipe - 03	ILHC-5830	1894*2310*135	Glass pipe/Aluminun frame		
		Plano - 01	Wunder CLS 2108	1988*1041*90	Tempered glass		
		Plano - 02	Wunder CLS 2510	1988*1218*90	Tempered glass		
	Accumulator	AC - 200	BST 200	1260*500		Hidronic system, Hot water system, Cold water system	
		AC - 300	BST 300	1400*550			
		AC - 500	BST 500	1695*650			

Calculation of the Solar Thermal System components

The catchment area and the capacity of the accumulator of the STS to supply the demand of domestic hot water are calculated. This process was done according to the Chilean law 20.365, and it was defined in an Excel spreadsheet in which were inserted input values needed for the final calculus.

This procedure requires data of: daily demand, housing demand, energy annual demand, solar fraction, the performance of the STS and the annual radiation collected. This last amount depends on of data extracted from the 3D model housing as the angle of roof and azimuth; and may vary according to the location of the house to assessing possibilities of adaptation of the STS.

The daily demand of hot water at a temperature of 45 °C is estimated, and daily hot water consumption per person regarded equal to 40 L/day (Cp) for single-family houses (Ministerio de Hacienda, 2010). Similarly, the number of

people who inhabit a house is calculated according to the values in Table 4, which serve as a basis for calculating the demand of domestic hot water of a housing (Dv) according to the following expression:

$$Dv = Cp * N^{\circ} \text{ of people}$$

Table 4. Number of people living in the house. Source: Ministerio de Hacienda (2010).

Room Amount	1	2	3	4	5	>5
People Amount	1.5	3	4	6	7	Room amount

Once calculated the demand for domestic hot water (Dv) it is proceed to calculate annual energy (DEacs), which represents the amount of energy required to raise the temperature of the flow of water from the inlet temperature of the cold water until the temperature at the points of consumption (Ministerio de Energía et al., 2010). It is calculated using the following expression:

$$DEacs = Q (Tu) * \rho * Cp * (Tu - Taf)$$

where:
DEacs = Annual energy demand
Q (Tu) = Water flow consumption
ρ = Water density
Cp = Specific Heat of water
Tu = Temperature of consumption of the water
Taf = Water inlet temperature

The solar fraction of the system (Fs), also called coverage or solar contribution, is the share of the energy demand covered by solar energy. The initial criterion of calculation is select the installation that justifies, as minimum, the compliance of the conditions established in the normative like minimum solar contribution depending on the geographical location (Ministerio de Energía et al., 2010).

In this case, (Ministerio de Hacienda, 2010) defines that the city of Concepcion belongs to the climate zone C, and therefore requires a minimum solar contribution of 57%. This is the value that will be taken as a basis for sizing the STS in a first step, then the most optimal value according to the catchment area of the solar collectors will be established.

The accurate of the efficiency of STS is regarded in the calculation process in which all their variables are interrelated, but its estimation facilitates the installations size assessment (Ministerio de Energía et al. 2010). Since this research focuses on the sizing of the STS to integrate into the architecture of a house in the early stages of the design, it will be taken as reference data from the work "Experimental validation of SDHW systems and parametric study on their performance based on dwelling characteristics" (Jerez, Cuevas, & Fissore, 2016), where the evaluation of a solar thermal system with flat collector annual simulation throws system efficiency of 45%.

This value matches the approximate estimation according to (Ministerio de Energía et al., 2010) which says that the average annual performance of the solar installation depends on the mean yield of the solar collectors, that 40-60% is usually included in the range. It is also estimated that the rest of the installation components introduce additional thermal losses that contribute to reducing this performance, these losses should never be higher than 20% and, therefore, values of average annual yield can be estimated for the complete installation within the range of 30 to 50%.

To calculate the solar collector's area is necessary to have the solar annual radiation value on a plane with the same orientation and inclination, which in this case is the roof side for an architectural integration of the panel. Then, this data is defined by the slope and the azimuth of the cover selected. These annual radiation values are taken from Meteonorm data of the Concepcion's airport (WMO Index number 856820) through a table created with different angles of inclination and azimuth (Table 5)

Finally, the collector area (Ac) allows to select the type and quantity of solar collectors to be used according to the parametric families, and is determined based on the following expression:

$$Ac * Ht * \eta NST = Fs * DEacs$$

where:
Ac = Collector surface

Ht = Global annual radiation
ηNST = Global performance of the solar installation
Fs = Solar Fraction
DEacs = Annual energy demand

The volume of the accumulation system depends on collectors area, using a specific value of 75 litre of accumulation per square meter of thecatchment (Ministerio de Energía et al., 2010). Maybe formed by one or more deposits accumulators and the volume total of them accumulators must be according with the demand and have a value that meets the following condition:

$$40 \leq V/A \leq 180$$

where:
A= Surface installed of STS
V= The accumulator volume

Table 5. Total annual Radiation (Kwh/m²) according to azimuth and slope in Concepción, Chile. Source: The author.

RADIATION									INCLUNATION												
AZIMUTH	0	5	10	15	20	25	30	35	37	40	45	50	55	60	65	70	75	80	85	90	TOTAL
-170	1533	1482	1424	1357	1284	1205	1123	1043	1010	963	885	810	738	670	608	552	508	479	459	442	18575
-160	1533	1484	1428	1363	1292	1217	1138	1058	1026	980	903	829	759	694	634	584	547	517	492	471	18949
-150	1533	1488	1434	1374	1307	1235	1161	1085	1055	1010	936	866	799	739	686	641	602	569	540	513	19573
-140	1533	1492	1444	1388	1326	1261	1192	1122	1095	1053	985	920	860	804	753	708	666	629	595	564	20390
-130	1533	1498	1455	1406	1351	1292	1230	1168	1143	1105	1044	985	928	875	826	779	736	695	657	621	21327
-120	1533	1505	1469	1426	1379	1327	1273	1218	1196	1162	1107	1053	1000	949	900	852	807	763	721	680	22320
-110	1533	1512	1484	1449	1409	1366	1319	1271	1251	1222	1172	1121	1071	1022	973	924	877	830	784	739	23329
-100	1533	1520	1500	1473	1441	1405	1366	1324	1307	1281	1235	1188	1141	1092	1043	993	943	894	844	795	24318
-90	1533	1529	1516	1498	1474	1445	1413	1377	1362	1338	1296	1252	1206	1158	1108	1057	1005	952	899	846	25264
-80	1533	1537	1533	1522	1506	1484	1458	1427	1413	1392	1353	1311	1266	1218	1167	1115	1060	1004	947	890	26136
-70	1533	1545	1549	1546	1537	1521	1500	1474	1462	1442	1406	1365	1321	1272	1220	1165	1108	1049	988	927	26930
-60	1533	1553	1564	1568	1565	1555	1539	1516	1506	1488	1453	1414	1369	1319	1266	1208	1148	1085	1020	954	27623
-50	1533	1560	1578	1588	1591	1586	1574	1554	1544	1528	1495	1456	1410	1360	1304	1244	1180	1113	1044	974	28216
-40	1533	1566	1590	1606	1613	1612	1604	1587	1578	1562	1530	1491	1445	1393	1335	1273	1205	1134	1061	985	28703
-30	1533	1571	1600	1620	1631	1634	1628	1613	1605	1590	1559	1520	1474	1420	1360	1294	1223	1148	1070	989	29082
-20	1533	1575	1607	1631	1645	1650	1647	1634	1626	1612	1581	1542	1494	1439	1378	1309	1235	1156	1073	987	29354
-10	1533	1577	1612	1638	1654	1661	1658	1646	1639	1625	1595	1555	1508	1452	1388	1318	1241	1159	1073	983	29515
0	1533	1578	1614	1640	1657	1665	1663	1652	1644	1631	1600	1561	1513	1457	1394	1323	1245	1162	1074	982	29588
10	1533	1577	1613	1639	1656	1663	1661	1649	1642	1629	1598	1560	1512	1456	1393	1323	1246	1164	1077	987	29578
20	1533	1576	1609	1634	1649	1655	1652	1640	1632	1618	1588	1550	1503	1448	1386	1318	1243	1164	1081	994	29473
30	1533	1572	1603	1624	1637	1641	1636	1623	1615	1601	1570	1532	1485	1432	1372	1306	1235	1159	1080	999	29255
40	1533	1568	1594	1611	1620	1621	1614	1598	1590	1575	1544	1506	1460	1408	1351	1287	1220	1148	1073	997	28918
50	1533	1562	1582	1595	1599	1596	1586	1568	1559	1543	1511	1472	1428	1377	1322	1261	1197	1129	1059	988	28467
60	1533	1555	1569	1576	1575	1567	1553	1532	1522	1505	1472	1433	1388	1339	1285	1228	1167	1103	1037	970	27909
70	1533	1548	1555	1554	1547	1534	1515	1491	1480	1461	1426	1386	1342	1293	1241	1186	1128	1068	1006	944	27238
80	1533	1540	1539	1531	1517	1498	1474	1445	1432	1412	1374	1333	1288	1240	1190	1136	1081	1024	966	908	26461
90	1533	1532	1522	1507	1486	1460	1430	1396	1381	1358	1318	1274	1229	1180	1130	1079	1026	972	918	864	25595
100	1533	1523	1506	1482	1453	1420	1383	1344	1327	1301	1257	1211	1163	1114	1065	1014	964	913	862	812	24647
110	1533	1515	1489	1457	1421	1380	1336	1290	1271	1242	1193	1143	1093	1043	994	944	896	848	801	755	23644
120	1533	1507	1474	1434	1389	1341	1289	1236	1214	1182	1127	1073	1021	969	919	871	824	779	736	694	22612
130	1533	1500	1460	1413	1360	1304	1245	1184	1159	1123	1062	1004	947	894	843	796	751	710	670	633	21591
140	1533	1494	1447	1394	1335	1271	1205	1136	1109	1068	1002	937	877	821	769	722	680	642	607	575	20624
150	1533	1489	1437	1378	1313	1244	1171	1096	1067	1022	950	880	814	754	700	654	614	579	548	521	19764
160	1533	1485	1430	1366	1297	1222	1144	1066	1035	989	913	840	770	704	644	593	554	523	498	476	19082
170	1533	1483	1425	1359	1286	1208	1127	1047	1015	968	890	816	744	675	613	557	512	483	461	444	18646
180	1533	1482	1423	1356	1282	1203	1120	1039	1007	959	881	806	733	664	600	544	497	466	447	432	18474

To relate the inputs and to calculate the solar collectors area in the case of study A, am spreadsheet was created in Excel and the equations and data identified previously were inserted (Table 6). In addition, a data base is created with the parametric families of already identified accumulators and solar collectors (Table 7). The area of each of these components is related to the calculated surface of collectors to select the type of collector and storage tank that fits better to the requirements of the system.

Table 6. Calculation of the STS in Excel. Source: The author.

Calculation of Collectors area and Accumulator capacity		
Inputs	Quantity	Unit
People Amount	4	
Daily demand	40	l/day
Domestic hot water consumption	160	l/day
Annual energy demand	2234.1	Kwh/year
Solar Fraction	57	%
Solar Thermal System efficiency	45	%
Angle	40	degree
Azimuth	0	degree
Total radiation	1631	KWh/m^{2}year
Outputs		
Collector area	1.74	m^2
Accumulator capacity	130.1	l

Table 7. Database of parametric families of the STS components. Source: The author.

Family	Family Type	Area (m^2)
Heat Pipe collector	Heat Pipe - 01	2.6
	Heat Pipe – 02	3.5
	Heat Pipe – 03	4.6
Plane collector	Plano – 01	2.0
	Plano – 02	2.4
Family	Family Type	Volume (l)
Accumulator	AC – 200	200
	AC – 300	300
	AC - 500	500

The Table 8 summarizes the information obtained, by selecting the category of collector to define the amount and type of family to be used. The solar fraction is set to the catchment area obtained with the collectors selected. The validation of the system allows to know if this complies with the minimum solar contribution required by the regulation of the law 20.365 determined by the following relationship:

$$CS \geq CSM * 0.85$$

where:
CS: Solar contribution of the STS [%].
CSM: Required minimum solar contribution [%].

In the case of study A (inclination 40º and azimuth 0 °) the applied methodology allowed to determine that it needs to be a catchment area of 1.74 m² and a capacity of the accumulator equal to 130.1 litres. To comply with these requirements, the database of solar thermal components integrated to the Excel table allowed determining two options of installation.

A first case where the collector called "Heat Pipe - 01" with an area of 2.6 m² provides a solar fraction of 85%, and a second case where the plane collector of type "plane - 01" of area equal to 2.0 m² obtains a solar fraction of 65.7%; both cases with an accumulator of 200 liters of capacity. To evaluate both options it is convenient to use the collector of the second alternative because its annual solar fraction does not exceed the critical value 75%, according to the F-Chart calculation program. Oversupply generate a thermal energy production increased to 90% in the summer months, producing risks of overheating of the STS (as it is the case of the Heat Pipe collector - 01).

Table 8. Summary of parametric families to use and checking of the minimum solar contribution of the STS. Source: the author.

Collector category: 1= Heat Pipe; 2= Plane collector			
2	Collector Area	Collector Type	Quantity
Collector to install	2	Plane - 01	1
Accumulator	200	AC-200	1
Solar contribution (CS) with the collectors selected (%)			65.7
Verification of minimum Solar contribution CS≥CSM*0.85 (48.45%)			YES

## Algorithm programmatic with Dynamo + Ladybug

Through the implementation of the algorithm with Dynamo language, has been devised with a set of operations that allows generating an exchange of information between the 3D Revit model and an Excel spreadsheet. In order to define the solar components to integrate into the STS depending on the house variables concerning orientation and inclination angle of the roof (Figure 3). Also the insertion point of the solar panels is defined according to the solar potential of the roof.

Figure 3. Relation of digital tools by algorithmic programming. Source: the author.
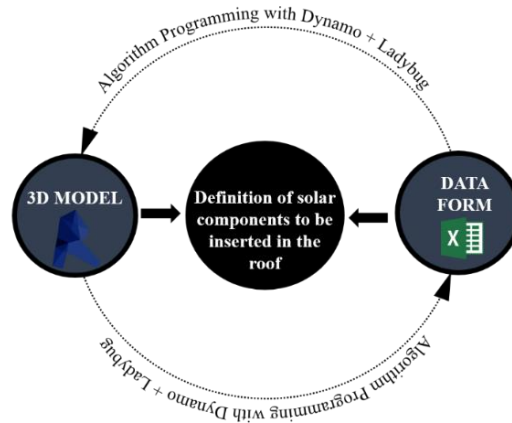
The interoperability of the software allows inserting in the table created in Excel the inputs that it needs to carry out the dimensioning of the STS according to the method established. Through Dynamo the node 1 is created and allows to identify the housing surface with greater solar potential according to the analysis performed with Ladybug as energy Simulator, which determines the levels of radiation incidents on each roof side and extracted parameters of inclination and azimuth angle that later with the node 2 are exported and inserted in the Excel spreadsheet (Figure 4).

Figure 4. Algorithmic programming to define the surface with greater solar potential and extract inclination and azimuth data to the STS calculation. Source: the author.
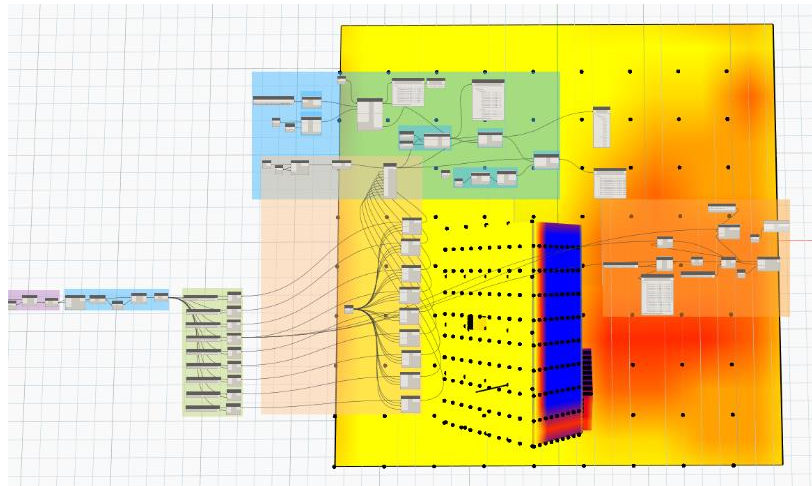
The relationship created starting from these nodes allows returning information to Dynamo with modifications defined in Excel. This condition allows to supplying the data in the algorithm relating to the type and amount of parametric families to insert in the model through the node 3. With this information, it is determined the insertion point of the solar collectors in the roof through a grid to indicate the point manually, and it is indicated the type of family to insert with the node 4 (Figure 4).

Finally, the algorithm created in Dynamo allows the inclusion of the parametric family of the solar collector and the storage tank in the housing type (Figure 5). This process regard that any variation in the configuration of the roof will affect directly the algorithmic programming created.

Figure 5. Insertion of parametric families in the model using the algorithmic programming. Source: the author.
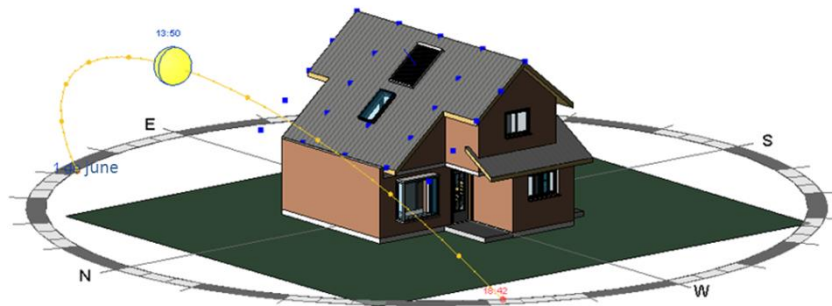
Piping system design with MEP

The design of piping systems with MEP utilities in Revit allows relating all the components of the STS inserted in the model, optimizing the routing and connections between the fittings and mechanical equipment. Three subsystems are identified: water cold system, hot water system and hydronic system. The latter is used for heat exchange, for heating or cooling processes for human comfort, using the liquid as a means of transport of heat (thermal energy), in this case it is represented by the closed circuit between the solar collector and the storage tank of the STS (Figure 6).

The tool selected allows creating the pipes circuits and doing the calculation of them according to the parameters already established of the accessories of parametric families, with the flow assigned to each type of this family. Also, it checks the behaviour of the installation in general and the need of making some change in the architecture of the house for its integration.

Figure 6. Piping system design with MEP. Source: the author.
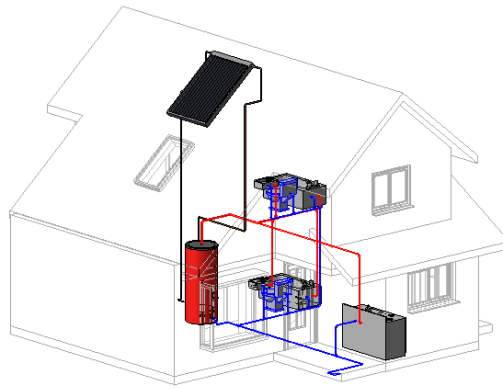
A parametric analysis based on two case-studies was done, exploring variations in the azimuth angle of the collectors with respect to the North to generate an array of 8 orientation possibilities (Figure 7). The analysis aims to identify changes in the type and number of solar components when the solar orientation of the house is modified (keeping in both cases a provision of 2234.1 Kwh/year).

In the first model, the azimuth angles between 0° and 90° required collection area between 1.71 m² and 2.12 m². Azimuth of - 135° and -180° increased this surface to 2.56 m² and 2.94 m², respectively. Recommending the use of a collector type "Plane - 01" for angles ranging from 0° to 45°, while for an azimuth of 90 ° is chosen a collector type "Plano - 02", both with an accumulator of type "AC - 200" to get a solar fraction less than 75% in the full set (critical value).

Figure 7. Variation of orientation in single family house type A according to the solar collector azimuth angle. Source: the author.
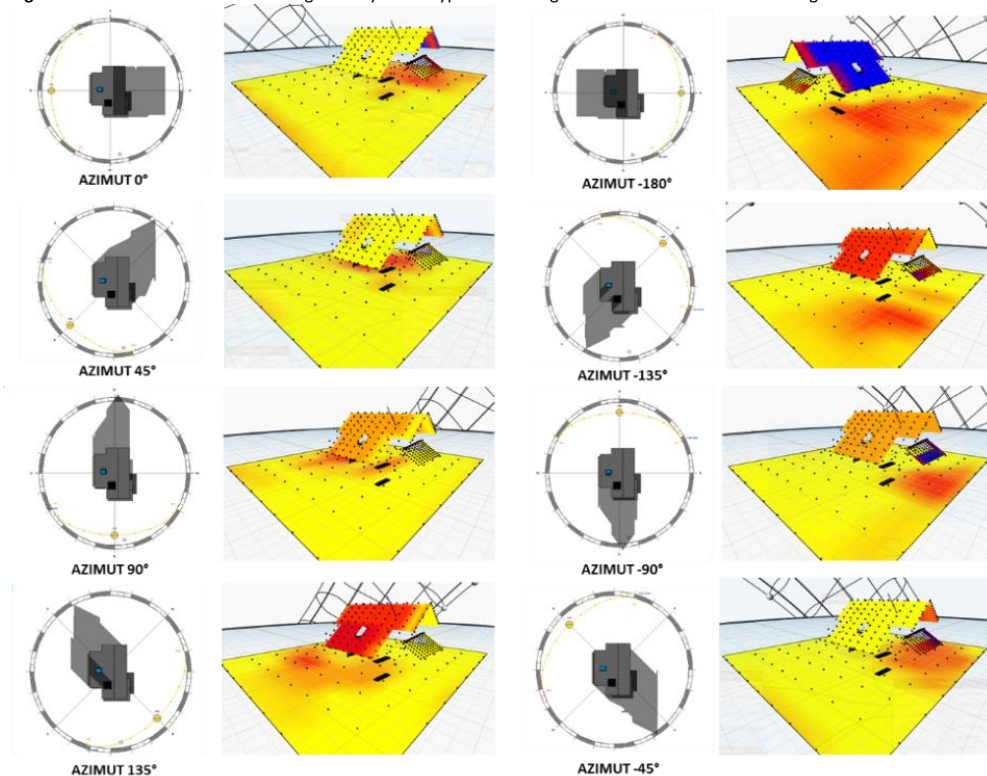
In contrast, to azimuth angles between 90° and 135° the Heat pipe collectors optimizes the STS operation, because the use of one collector type "Heat Pipe - 01" with an accumulator "AC-200" adjusts the solar fraction to values close to 70%. The Chart 2 shows that for orientations opposite to the solar travel (- 135 ° and 180 °), the types "Heat Pipe - 01" and "Heat Pipe-02" give less than 75% solar fraction, which is an optimal option to use in housing.

Figure 8. The amount and type of solar components. Case of study A. Source: the author.

	AC - 200 Heat Pipe - 01 1	AC - 300 Heat Pipe - 02 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1
	AC - 200 Plane - 2 1	AC - 300 Plane - 1 2	AC - 300 Plane - 1 2	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 2 1	AC - 300 Plane - 1 2
Azimut	-90	-180	-135	-45	0	45	90	135
Solar Fraction - Plane Collector	64.6	77.5	89	62.9	65.7	63.4	65.6	90.48
Solar Fraction - Heat Pipe Collector	70.1	67.89	57.8	81.8	85.4	82.4	71.12	58.81

The second case-study (Figure 9) changes the roof inclination to 27 °, obtaining a similar behaviour to the previous one in orientations with an azimuth between 0° and 90°. However, solar collector area decreases between 2.17 m² and 2.35 m² respectively for opposite orientations to the solar travel (azimuth - 135 ° and 180 °). The behaviour of the plane collectors generates a solar fraction of the system less than 67% in all orientations, then it recommends the use of a collector type "Plane - 01" with accumulator "AC-200" for all the alternatives that are within the solar travel (from 0° to 90° azimuth). Changing the type to "Plane - 02" when it has an opposite direction to the North (-135 ° and -180 °).

Figure 9. Variation of orientation in housing type B according to the angle of azimuth of the solar collector. Source: the author.
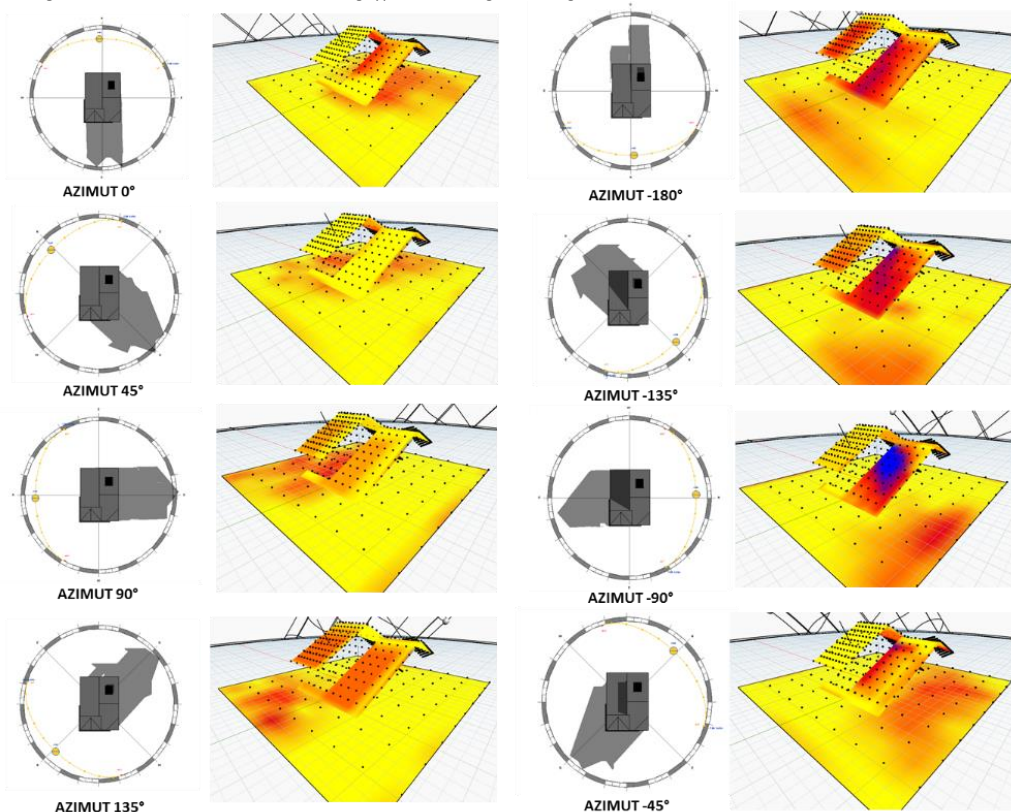
The roof inclination of 27° has a requirement of catchment surface lower by the Heat pipe collector, demonstrating it in the fraction solar values that generate in the STS with orientations between 0° and 90°, with percentages higher to the critical value (75%). However, as in the case of study A, the performance of these collectors are optimized in positions contrary to the solar trajectory (135°,-135° and -180°) using a collector "Heat Pipe-01" and accumulator "AC-

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200" gets a solar fraction not greater to the 68%, which is superior by the plane collectors in this orientation (Figure 10).

Figure 10. Amount and type of solar components, case-study B. Source: the author

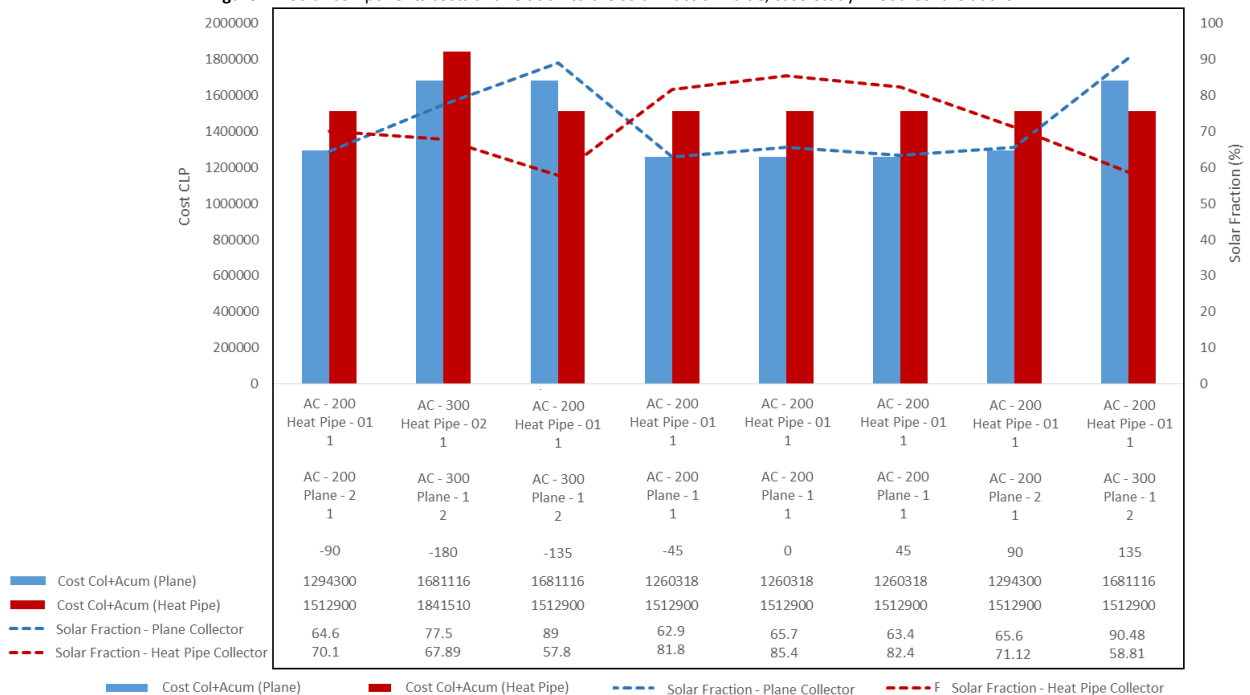|	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1
	AC - 200 Plane - 1 1	AC - 200 Plane - 2 1	AC - 200 Plane - 2 1	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 2 1
Azimut		-180	-135		0	45	90	135
Solar Fraction - Plane Collector	58.2	63.04	62.4	65	67	65.3	58.8	58.2
Solar Fraction - Heat Pipe Collector	76.4	63.11	67.6	84	87.2	84.8	76.4	68.29

■ Solar Fraction - Plane Collector ■ Solar Fraction - Heat Pipe Collector

The analysis determined that the plane collectors types are adapted to efficient way in housing with roof side positive to the solar trajectory, and when the STS is orientated opposite to the solar trajectory can be optimize with Heat pipe collectors to increase the solar fraction of the system, between 10% and 20% depending on each case. Also, the inclination angle of 27 ° contributes to improving its behaviour energy since the collectors solar receive greater amount of solar annual radiation.

Incorporating the costs of the accumulator and solar collector in the parametric analysis, helps to determine that there is a directly proportional relation between these parameters with the solar fraction value that contributes the STS. In the case-study A, the costs associated with the plane collector type, expressed in Figure 11, shows that it generates an excessive solar contribution of the system with azimuth angles between 135 ° and 180 °, which decreases its economic feasibility.

Figure 11. Solar components costs and relation to the solar fraction value, case-study A. Source: the author.

	AC - 200 Heat Pipe - 01 1	AC - 300 Heat Pipe - 02 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1
	AC - 200 Plane - 2 1	AC - 300 Plane - 1 2	AC - 300 Plane - 1 2	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 2 1	AC - 300 Plane - 1 2
	-90	-180	-135	-45	0	45	90	135
Cost Col+Acum (Plane)	1294300	1681116	1681116	1260318	1260318	1260318	1294300	1681116
Cost Col+Acum (Heat Pipe)	1512900	1841510	1512900	1512900	1512900	1512900	1512900	1512900
Solar Fraction - Plane Collector	64.6	77.5	89	62.9	65.7	63.4	65.6	90.48
Solar Fraction - Heat Pipe Collector	70.1	67.89	57.8	81.8	85.4	82.4	71.12	58.81

■ Cost Col+Acum (Plane) ■ Cost Col+Acum (Heat Pipe) - - - Solar Fraction - Plane Collector - - -F Solar Fraction - Heat Pipe Collector
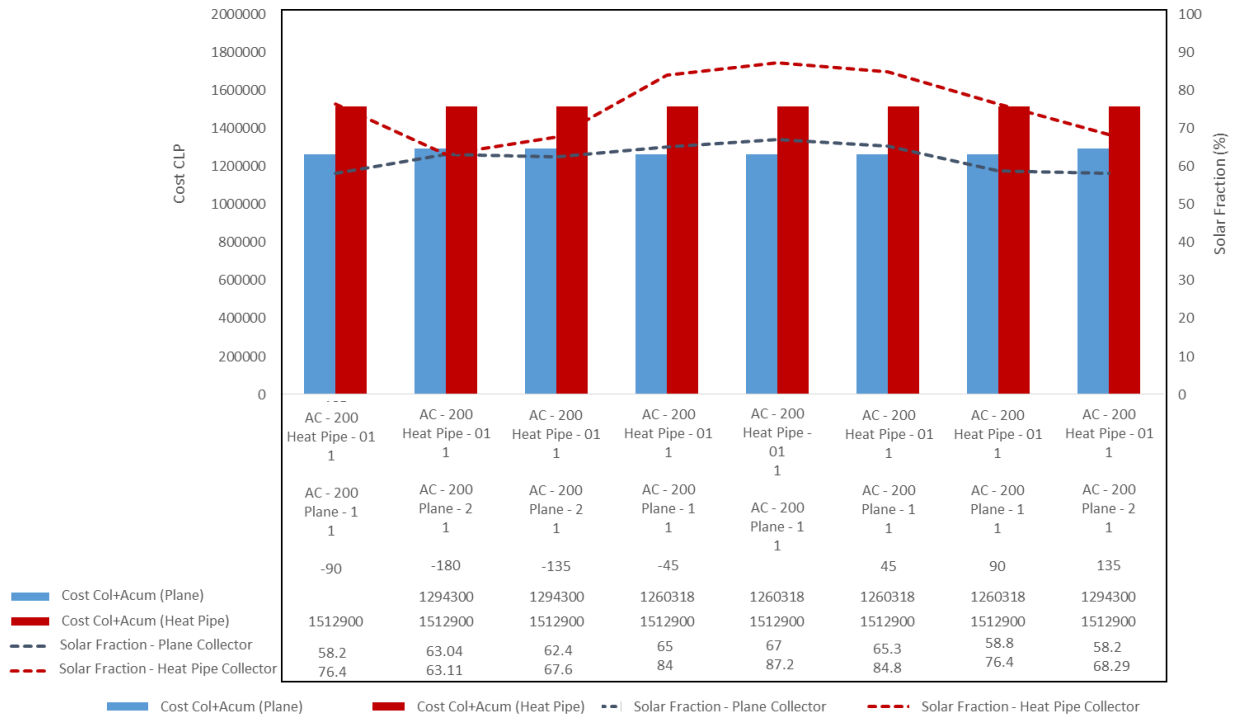
To know the economic feasibility of the STS with the use of Heat pipe collectors type, the Figure 11 shows how the use of these components generates two different scenarios. In a first case, it has a cost less of 168.216 CLP (Chilean Pesos)

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in orientation -135 °, representing a 10% less than the investment for collectors plane. In a second case it has an extra cost of 160.400 CLP for orientations - 180 ° (9.5%). Demonstrating that the selection of these collectors improves the solar fraction values and requires an investment with little room for variation with regard to the alternative of plane collectors.

To analyze the case-study B, in the Figure 12 it is observes that the costs corresponding to install the plane collectors are similar, particularly the cost of solar components of type "plane – 01" presents a cost of 1.260.318 CLP with variation of a 4%, to the change to type "Plane – 02", representing a viable economic alternative.

	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1	AC - 200 Heat Pipe - 01 1
	AC - 200 Plane - 1 1	AC - 200 Plane - 2 1	AC - 200 Plane - 2 1	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 1 1	AC - 200 Plane - 2 1
	-90	-180	-135	-45		45	90	135
Cost Col+Acum (Plane)		1294300	1294300	1260318	1260318	1260318	1260318	1294300
Cost Col+Acum (Heat Pipe)	1512900	1512900	1512900	1512900	1512900	1512900	1512900	1512900
Solar Fraction - Plane Collector	58.2	63.04	62.4	65	67	65.3	58.8	58.2
Solar Fraction - Heat Pipe Collector	76.4	63.11	67.6	84	87.2	84.8	76.4	68.29

However, the type Heat pipe allows to improving the fraction solar of the system in a 15% and 23% in orientations 135 ° and 90 ° respectively, with an increase of 20% respect to the cost of the plane collectors. These values allow inferring that there are no substantial differences between installing one or other component, according to the recommendations made at the monetary approach, the efficiency STS to install lies in the evaluation of the solar contribution depending on its orientation which proportionally affects the cost of its components.

Finally, interoperability of employed tools allows visualization of the housing with the STS integrated through the creation of render images (figure 13), demonstrating that both collectors types have the flexibility to be adapted in the roof of the house under the architectural integration criteria. By attaching to existing elements such as skylights and by adding a new function of solar filter that allows incorporating daylight in the living spaces (with type Heat pipe).

Figure 13. Integration of solar collectors in case study A (left) and case study B (right). Source: the author.

Conclusions

The study obtained an integrated design method to assess and integrates solar thermal systems in single houses that allowed to select products, insert and adapts automatically the parametric designs into the digital model. This method includes a solar products characterization and modeling of parametric families of each component, calculation of the solar energy potential of the housing roof, evaluation of the solar components according to demand of domestic hot water (HWS), quantification and integration of the solar thermal system (STS) in the housing model, layout of

plumbing, budget and visualization of architectural integration. It identifies the type and number of components used in the STS based on its energy performance, which facilitates its incorporation in early stages of design.

The characteristics of solar components linked through algorithmic programming created in Dynamo in conjunction with Ladybug as energy simulator, allows the designer to select the more favorable location of the solar collector according to architectural and environmental needs, as well as exploring different alternatives of design. It generates opportunities of customizing the STS directly in the building without requiring data detailed of the project, achieving get results more optimal to reduce the possibilities of overproduction of energy thermal.

This experience allowed demonstrating the integration of solar thermal systems in the early design of houses, with the configuration of equipment according to the roof inclination, orientation, layout of pipes and accessories. It can be applied to more products, different geographic locations and designs of houses or buildings with a similar methodology. Particularly in early stages of building design with a quick energy performance evaluation and configuration to incorporate more properly these systems, to maintain architectural features and to reduce the environmental impact of buildings´ occupation.

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