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Assessment of CO_2 Emissions Reduction Based on Different Insulation Materials in Residential Buildings: Example from Turkey

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Abstract. In this study, the reduction of CO_2 emissions caused by energy savings due to thermal insulation materials applied to the exterior of buildings was investigated. The study includes the evaluation of four different insulation materials including XPS, EPS, PUR and Rock Wool in terms of the reduction potential of CO_2 emissions for all city centers in Turkey. Moreover, the optimum insulation thicknesses of the buildings that have both heating and cooling needs were determined for these insulation materials by means of Life Cycle Cost Analysis. The annual energy needs per unit area of the external walls of the buildings, which are insulated according to their optimum insulation thickness were determined and correspondingly the amount of fuel needed to meet this energy was calculated. In the study, CO_2 emission values released from buildings to atmosphere were compared in terms of fuel amounts obtained from total energy demands during heating supplied from natural gas and cooling supplied from electricity of the residential buildings insulated with diverse insulation materials. Consequently, when CO_2 reduction potentials of the buildings insulated with materials in the optimum insulation thickness are compared with those of the uninsulated buildings, insulation material providing highest potential in CO_2 emission mitigation was to be found as Rock wool.

1. Introduction

Today, climate change resulted from greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs) and nitrous oxide (N_2O) released into the atmosphere owing to consumption of fossil fuels is one of the most severe problems threatening to our world. When the impacts of the greenhouse gas emissions are compared, it is seen that the most contributor gas to climate change is carbon dioxide [1]. The increase in GHGs because of energy consumption based on the growth of population and improvements in industrial sectors is expected to reach by approximately 30 % by 2040 [2] and this increase will significantly trigger to increase in the atmospheric temperature giving rise to many problems, like increasing sea level rise [3]. According to the data of 2016, it has been stated that approximately 40% of the total energy consumption among the global energy consumption sectors was stemmed from the residential buildings. The carbon dioxide emissions based on the energy consumption of residential buildings consists of approximately 35% of those emitted globally [4]. Most of the energy spent for heating and cooling needs of buildings in case of that they are not insulated or well insulated is disappeared and this situation triggers to some issues, such as environmental problems [5].For this reason, insulation materials with high thermal qualities to be applied to buildings will be effective in the reduction of the energy consumption of buildings especially resulting from their air conditioning requirements and correspondingly they will contribute to decrease CO_2 emissions produced during energy consumption [6] Furthermore, 35% of Turkey's total energy is used by buildings, and 65% of this energy is used in the air conditioning of buildings [7]. Moreover, approximately 60-80% of the thermal loads that are lost in buildings is resulted from heat transfer through conduction and convection on the outer walls of the buildings [8]. Referring to these information, all city centers in Turkey were considered and the relationship between external thermal insulation on buildings and CO_2 emissions caused by the buildings was investigated in the present work. As a result, the potential reduction of CO_2 emissions through the thermal insulation of the residential buildings in Turkey was determined.

2. Materials and method

Natural gas has started to be used to meet the energy needs required for heating in almost all buildings in all city centers of Turkey since year of 2019. That’s why, heating energy was supplied from natural gas and also this study was benefit from electrical energy for cooling needs in the residential buildings and so mitigation of CO_2 emissions based on the usage of thermal insulation materials was evaluated under these assumptions. Furthermore, another assumption was that the thermal insulation was only applied to the outer walls of the buildings and also from the outside of these walls. Thickness of the thermal insulation was determined by means of Life Cycle Cost Analysis (LCCA) considering both the heating and cooling needs of the buildings. The energy demands of the buildings were determined by regarding the insulated and uninsulated walls. Consequently, the CO_2 emission values, resulted from fuel consumption due to the total energy demands based on heating and cooling needs of residential buildings, to be released into the atmosphere were determined. Equations and parameters required for calculations are presented in the following sections.

2.1. Properties of external walls and insulation materials and required parameters

The schematic representation of the external wall and the insulated wall taken as reference in the present study is presented in Figure 1, and the necessary parameters for the calculations are presented in Table 1. The thermal insulation materials examined can be listed as extruded polystyrene foam (XPS), expanded polystyrene foam (EPS), polyurethane rigid foam (PUR) and rock wool (RW), which are mostly preferred as thermal insulation materials in the construction sector in Turkey.

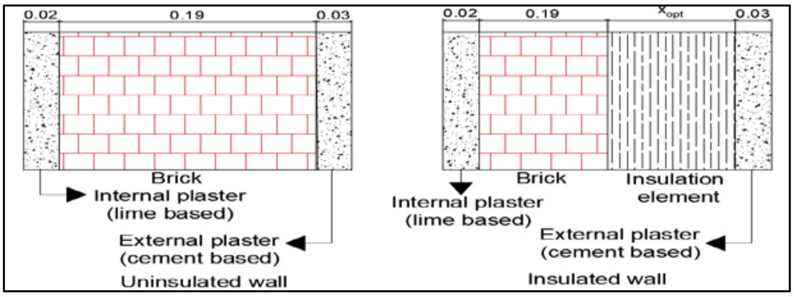

Figure 1. Schematic representation of the insulated and uninsulated wall.

Table 1. Parameters of walls, insulation materials and fuels [9, 10].

Wall structure	Pressure resistance MPa	Density (kg/m^3)	Thickness (m)	k (W/mK)	R (m^{2}K/W)
Internal plaster (lime based)	-	1200	0.020	0.87	0.029
Brick	≥13.2	750	0.190	0.50	0.380
External plaster (cement based)	-	2100	0.030	1.40	0.025
R_i	-	-	-	-	0.130
R_o	-	-	-	-	0.040

$R_{w,t}$ (uninsulated)	-	-	-	-	0.604
Insulation Material	Thermal conductivity k (W/mK)	Heat transfer resistance R (m^2K/W)		Cost C_y ($\$/m^3$)	
XPS	0.030	1.333		150	
EPS	0.035	1.143		100	
PUR	0.025	1.600		220	
RW	0.040	1.250		70	
Fuel	Hu	η	COP	Price (C_{fuel}, C_e)	
Natural gas	34.485×10^6 J/m^3	0.90	-	0.232 \$/m^3	
Electricity	3.5990×10^6 J/kWh	-	2.5	0.0912 \$/kWh	

2.2. Degree-Day method, heating and cooling loads and life cycle cost analysis

By means of the Degree-Day method, the energy demand for the residential buildings can be estimated from a reference temperature (equilibrium temperature). In this study, Degree-Day (DD) numbers were taken from the Turkish State Meteorological Service (TSMS) [11]. In the calculation of DD values, equilibrium temperatures for the number of heating DD (HDD) and cooling DD (CDD) were accepted as 15 ^oC and 22 ^oC, respectively by TSMS. The annual heat loss from the unit surface area of the external walls of the buildings heated or cooled with HDD and CDD values can be calculated with the help of Equation 1.

$$q_{year} = 86400 \; x \; DD \; x \; U \tag{1}$$

In Equation 1, q_{year} expresses the annual heat loss (W/m^2). Considering heating, DD value will be equal to HDD value and also it will be taken as CDD for cooling conditions. The U value in the equation indicates the total heat transfer coefficient, and its value can be calculated from Equation 2.

$$U = \frac{1}{R_i + R_w + (\frac{x}{k}) + R_o} \tag{2}$$

In Equation 2, R_i and R_o values are the heat transfer resistance of area surrounding the wall internally and externally, and R_w is the heat transfer resistance of the uninsulated wall (m^{2}K/W). Moreover, x is the insulation thickness (m) and k is the thermal conductivity coefficient (W/mK) of the insulation material. The annual heating and cooling energy demand for the unit area of the outer walls can be calculated using Equations 3 and 4 [12]. In addition, the formula showing the amount of fuel to meet this energy need was presented in Equation 5, in which *Hu* expresses the low heat value of fuel (see Table 1).

$$E_{year,H} = \frac{86400 \; x \; HDD}{\left(R_{w,t} + (\frac{x}{k})\right) \; x \; \eta} \tag{3}$$

$$E_{year,C} = \frac{86400 \; x \; CDD}{\left(R_{w,t} + (\frac{x}{k})\right) \; x \; COP} \tag{4}$$

$$\dot{m}_{fuel} = \frac{E_{year}}{Hu} \tag{5}$$

Life Cycle Cost Analysis (LCCA) was used to determine the optimum insulation thickness for the residential buildings. This analysis method is based on the energy-cost analysis of the investment over an estimated period. Accordingly, total heating costs over a period of *N* years are evaluated using the

present worth factor (*PWF*) depending on inflation and interest rates. It can be calculated from formulas
given below.

$$r = \frac{i-g}{1+g} \tag{6}$$

$$PWF = \frac{(1+r)^N - 1}{r\, x\, (1+r)^N} \tag{7}$$

In the Equations 6 and 7, i is the interest rate, r is real interest rate, g is the inflation rate and N is the life time and they can be accepted as 12.5%, 0.059, 11.75% and 10 years, respectively. Correspondingly,
PWF value was found as 9.640 thanks to Equations 6 and 7 and financial values used in the calculations.

As a result, the expression giving the optimum insulation thickness that will minimize the total air conditioning cost for heating and cooling purposes is given in Equation 8 [13].

$$X_{opt,H,C} = 293.94 \times \left(\frac{HDD \times C_{fuel} \times PWF \times k}{Hu \times C_y \times \eta} + \frac{CDD \times C_e \times PWF \times k}{C_y \times COP}\right)^{1/2} - k \times R_{w,t} \tag{8}$$

In Equation 8, C_{fuel}, c_e and c_y represent the unit prices of natural gas ($/m^3), electrical energy ($/kWh) and the insulation material ($/m^3), respectively.

2.3. Calculation of emission values
When the composition of natural gas including 85% methane (CH_4), 7% ethane (C_2H_6), 3% propane (C_3H_8) and 2% butane (C_4H_{10}) is considered, the formula of natural gas used to meet heating needs can be expressed as in Equation 9 [13].

$$C_{1.16}H_{3.71} + 4.17(O_2 + 3.76N_2) \rightarrow 1.16CO_2 + 1.85H_2O + 15.6N_2 \tag{9}$$

When it is assumed that natural gas burns with 90% efficiency, 2.05 kg of CO_2 is approximately released into the atmosphere as a result of the burning of 1 m^3 of natural gas according to the chemical formula given in Equation 9 (1 kmol of natural gas was taken as approximately 22.4 m^3). Data belonging to energy sources used in Turkey for generation of electricity in 2019 were used to determine the amount of CO_2 emissions resulted from the consumption of electrical energy used for cooling needs of the buildings. The distribution of electrical power generation and CO_2 emission amounts based on sources were investigated and the values are presented in Table 2 [14].

Table 2. Sources of electricity power generation and CO_2 emission values in Turkey [14].

Energy Source	**Production (GWh)**	**Contribution (%)**	**Greenhouse gas emission (Tone CO_2 / GWh)**	**Greenhouse gas emission (Tone-CO_2)**
Import coal	60,394.7	19.87	888	53,630,493.6
Hard coal + Asphalted	5,627.2	1.85	888	4,996,953.6
Lignite	46,872.2	15.42	1054	49,403,298.8
Natural gas	57,288.2	18.85	499	28,586,811.8
Liquid Fuels	336.0	0.11	753	246,288
Dam	65,926.2	21.69	26	1,714,081.2
Sea, Lake and Stream	22,896.6	7.53	26	595,311.6
Wind	21,730.7	7.15	10	217,307
Biomass energy	4,624.2	1.52	26	120,229.2
Geothermal	8,951.7	2.95	38	340,164.6

Solar	9,249.8	3.04	23	212,745.4
TOTAL	**303,897.6**	**100.00**	**4211**	**140,063,684.80**

In accordance with Table 2, the amount of CO_2 emissions released to the environment from production of 1kWh of electrical energy was found as 0.461 kg.

3. Findings and discussion

The optimum insulation thickness of the outer walls was determined by means of the formula given in Equation 8. Comparison of the optimum thickness values of the insulation materials was presented in Figure 2. Correspondingly, when the optimum insulation thicknesses of the insulation materials that will minimize the total air conditioning cost are compared, it is seen that the thinnest insulation material is PUR while the thickest insulation material is RW. Moreover, it can be easily seen from Figure 2 that the insulation thickness increases with respect to the increase in DD values.

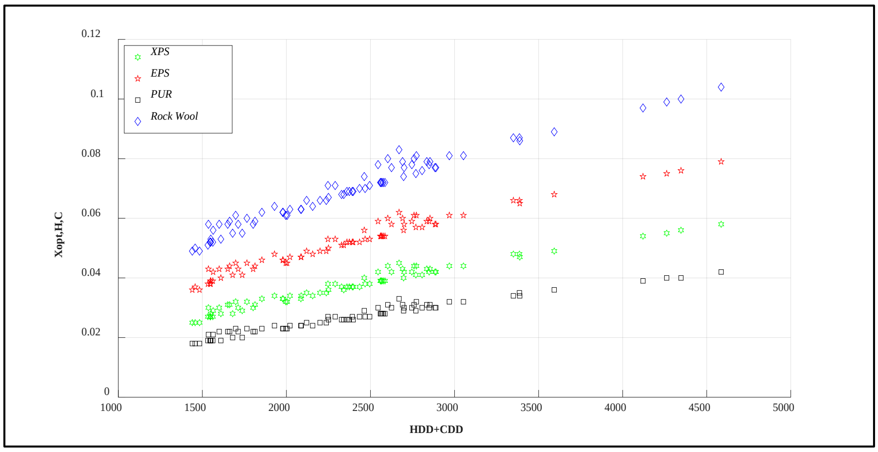

Figure 2. Variation of optimum insulation thickness according to DD numbers of insulation

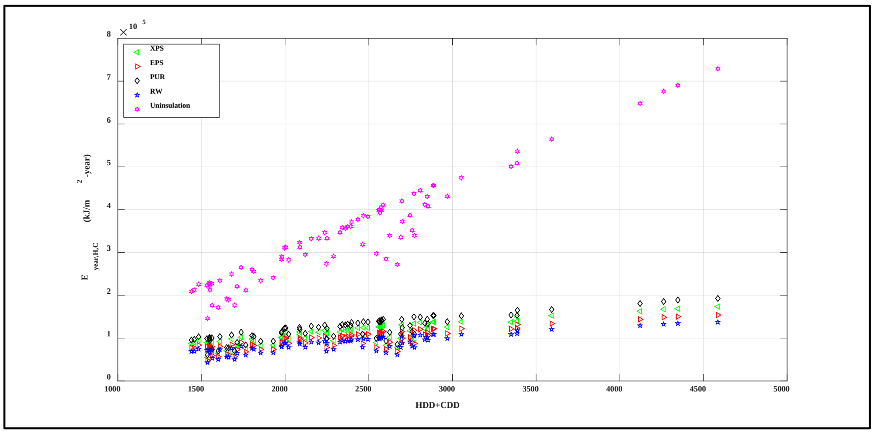

Figure 3. Change of annual energy requirement for unit area of walls with DD values.

The amount of energy that will meet the heating in winter and cooling in summer was calculated with the help of Equation 3 and 4 as shown in Figure 3. The annual total energy amount per the unit area in case of usage of four different insulation materials applied to uninsulated external walls is exhibited in Figure 3. In accordance with Figure 3, it can be easily expressed that the buildings insulated with PUR material showed the most energy demand, while the energy saving of the buildings insulated with RW material demonstrated the best results.

The amount of fuel needed for the buildings, which energy needs per unit area were determined, were calculated with the help of Equation 5. The amount of fuel to be met the energy needed according to the insulation materials shows a similar trend with the amount of energy presented in Figure 3. The annual fuel amounts have been multiplied by CO_2 emission values based on type of insulation materials and results obtained from this calculation are presented in Table 3. Comparisons of CO_2 emission values based on the insulation materials and DD values are also demonstrated in Figure 4. In accordance with the variation in distribution of CO_2 emissions released from buildings during heating and cooling based on *HDD+CDD* values, insulation materials have a remarkable impact on the reduction of the emission amounts (see Figure 4). The relative order of potential reduction of CO_2 emissions for different insulation materials was RW > EPS > XPS > PUR (see Figure 4). Another major result obtained from Figure 4, CO_2 emission values of the buildings in the cities with DD numbers bigger than 3000 ^{0}C-day showed a very fast increase trend than other cities with lower DD values.

Table 3. CO_2 emission values according to insulation material used in all city centers of Turkey.

m_{CO_2}, (kg/m^2-year) under uninsulation and insulation conditions													
				Uninsulation		XPS		EPS		PUR		RW	
No	City	HDD	CDD	Heat.	Cool.	Heat.	Cool.	Heat.	Cool.	Heat.	Cool.	Heat.	Cool.
1	**Adana**	785	913	8.215	6.677	2.969	2.414	2.358	1.917	3.619	2.942	1.881	1.529
2	**Adıyaman**	1490	1055	15.58	7.716	4.698	2.325	3.663	1.813	5.870	2.905	2.939	1.454
3	**Afyonkarahisar**	2335	100	24.42	0.731	8.031	0.240	6.313	0.189	9.811	0.294	5.024	0.150
4	**Ağrı**	4050	71	42.37	0.519	10.64	0.130	8.335	0.102	13.44	0.165	6.669	0.082
5	**Amasya**	1897	191	19.84	1.397	6.900	0.486	5.522	0.389	8.538	0.601	4.433	0.312
6	**Ankara**	2169	191	22.69	1.397	7.460	0.459	5.864	0.361	9.320	0.574	4.720	0.291
7	**Antalya**	788	812	8.248	5.938	3.104	2.236	2.444	1.761	3.723	2.682	1.962	1.414
8	**Artvin**	1944	60	20.34	0.438	7.353	0.159	5.839	0.126	8.963	0.193	4.658	0.101
9	**Aydın**	954	697	9.979	5.097	3.682	1.880	2.959	1.511	4.508	2.302	2.376	1.213
10	**Balıkesir**	1679	299	17.56	2.187	6.227	0.775	4.964	0.618	7.741	0.964	3.973	0.495
11	**Bilecik**	2002	84	20.94	0.615	7.424	0.218	5.828	0.171	9.011	0.264	4.679	0.137
12	**Bingöl**	2570	399	26.89	2.918	7.843	0.851	6.158	0.668	9.721	1.055	4.915	0.533
13	**Bitlis**	3531	62	36.94	0.454	9.973	0.122	7.773	0.095	12.36	0.152	6.249	0.077
14	**Bolu**	2583	3	27.02	0.022	8.573	0.007	6.790	0.006	10.61	0.009	5.434	0.004
15	**Burdur**	2010	240	21.03	1.755	7.041	0.588	5.594	0.467	8.637	0.721	4.477	0.374
16	**Bursa**	1497	316	15.66	2.311	5.778	0.853	4.569	0.674	7.074	1.044	3.680	0.543
17	**Çanakkale**	1209	504	12.65	3.686	4.763	1.388	3.750	1.093	5.713	1.665	3.011	0.877
18	**Çankırı**	2465	110	25.79	0.804	8.181	0.255	6.480	0.202	10.13	0.316	5.185	0.162
19	**Çorum**	2544	31	26.61	0.226	8.443	0.072	6.687	0.057	10.45	0.089	5.352	0.046
20	**Denizli**	1256	598	13.13	4.374	4.658	1.550	3.713	1.236	5.791	1.927	2.972	0.989
21	**Diyarbakır**	1907	852	19.95	6.231	5.820	1.818	4.569	1.427	7.360	2.299	3.684	1.151
22	**Edirne**	1642	379	17.18	2.772	5.973	0.964	4.780	0.771	7.390	1.192	3.837	0.619
23	**Elazığ**	2259	487	23.63	3.562	7.123	1.073	5.553	0.837	8.900	1.341	4.455	0.671
24	**Erzincan**	2628	221	27.49	1.617	8.287	0.487	6.460	0.380	10.35	0.609	5.183	0.305
25	**Erzurum**	4339	8	45.39	0.059	11.09	0.014	8.740	0.011	14.15	0.018	6.964	0.009
26	**Eskişehir**	2301	96	24.07	0.702	7.914	0.231	6.221	0.181	9.887	0.288	5.007	0.146
27	**Gaziantep**	1751	712	18.31	5.207	5.712	1.623	4.478	1.273	7.045	2.002	3.603	1.024
28	**Giresun**	1270	187	13.29	1.368	5.584	0.575	4.368	0.450	6.666	0.686	3.534	0.364
29	**Gümüşhane**	2740	30	28.66	0.220	8.786	0.067	6.915	0.053	11.02	0.084	5.578	0.043
30	**Hakkâri**	3095	291	32.38	2.128	8.874	0.583	6.975	0.458	11.04	0.726	5.582	0.367
31	**Hatay**	1091	674	11.41	4.930	4.127	1.782	3.277	1.415	5.030	2.172	2.648	1.143
32	**Isparta**	2209	165	23.11	1.207	7.597	0.397	5.972	0.312	9.492	0.496	4.807	0.251
33	**Mersin**	574	962	6.003	7.035	2.261	2.649	1.780	2.086	2.782	3.259	1.430	1.675
34	**İstanbul**	1509	171	15.78	1.250	6.203	0.491	4.839	0.383	7.505	0.594	3.912	0.310
35	**İzmir**	857	707	8.965	5.170	3.448	1.988	2.702	1.558	4.153	2.395	2.192	1.264
36	**Kars**	4253	9	44.49	0.066	11.02	0.016	8.658	0.013	13.87	0.021	6.884	0.010
37	**Kastamonu**	2798	9	29.27	0.066	8.972	0.020	7.061	0.016	11.02	0.025	5.636	0.013
38	**Kayseri**	2613	84	27.33	0.615	8.523	0.192	6.683	0.150	10.51	0.236	5.377	0.121
39	**Kırklareli**	1735	245	18.15	1.792	6.434	0.635	5.130	0.506	7.999	0.790	4.105	0.405
40	**Kırşehir**	2367	128	24.76	0.936	7.996	0.302	6.309	0.239	9.945	0.376	5.035	0.190
41	**Kocaeli**	1310	238	13.70	1.741	5.504	0.699	4.348	0.552	6.690	0.850	3.542	0.450
42	**Konya**	2415	151	25.26	1.104	8.015	0.350	6.348	0.277	9.927	0.434	5.080	0.222
43	**Kütahya**	2402	66	25.13	0.483	8.114	0.156	6.403	0.123	10.09	0.194	5.168	0.099
44	**Malatya**	2142	558	22.41	4.081	6.754	1.230	5.335	0.971	8.439	1.537	4.269	0.777
45	**Manisa**	1282	647	13.41	4.732	4.663	1.645	3.676	1.297	5.770	2.036	2.960	1.044
46	**Kahramanmara**	1424	823	14.89	6.019	4.810	1.943	3.796	1.534	5.983	2.417	3.029	1.224

47	**Mardin**	1786	905	18.68	6.618	5.540	1.962	4.334	1.535	6.893	2.442	3.486	1.235
48	**Muğla**	1705	415	17.83	3.036	6.085	1.035	4.816	0.819	7.496	1.275	3.842	0.654
49	**Muş**	3037	313	31.77	2.289	8.708	0.627	6.844	0.493	11.04	0.796	5.477	0.395
50	**Nevşehir**	2499	64	26.14	0.468	8.294	0.148	6.569	0.118	10.27	0.184	5.257	0.094
51	**Niğde**	2467	92	25.81	0.672	8.188	0.213	6.485	0.169	10.14	0.264	5.190	0.135
52	**Ordu**	1384	165	14.48	1.207	5.815	0.485	4.675	0.390	7.068	0.589	3.742	0.312
53	**Rize**	1394	216	14.58	1.580	5.730	0.621	4.547	0.492	7.119	0.771	3.716	0.402
54	**Sakarya**	1354	208	14.16	1.521	5.689	0.611	4.494	0.483	6.915	0.743	3.661	0.393
55	**Samsun**	1331	202	13.92	1.478	5.592	0.593	4.496	0.477	6.798	0.721	3.651	0.387
56	**Siirt**	1777	996	18.58	7.284	5.423	2.125	4.258	1.668	6.721	2.633	3.399	1.332
57	**Sinop**	1217	333	12.73	2.435	5.003	0.957	4.039	0.773	6.215	1.189	3.244	0.620
58	**Sivas**	2862	27	29.94	0.198	9.025	0.060	7.128	0.047	11.27	0.074	5.704	0.038
59	**Tekirdağ**	1543	259	16.14	1.894	6.079	0.713	4.786	0.562	7.291	0.855	3.843	0.451
60	**Tokat**	2050	106	21.44	0.776	7.456	0.270	5.878	0.212	9.227	0.334	4.732	0.171
61	**Trabzon**	1245	195	13.02	1.426	5.474	0.599	4.361	0.477	6.534	0.715	3.516	0.385
62	**Tunceli**	2453	382	25.66	2.794	7.609	0.828	6.030	0.656	9.467	1.031	4.788	0.521
63	**Şanlıurfa**	1336	1267	13.97	9.266	4.077	2.703	3.242	2.149	5.156	3.418	2.581	1.711
64	**Uşak**	2039	161	21.33	1.177	7.277	0.402	5.759	0.318	8.964	0.495	4.595	0.254
65	**Van**	2945	108	30.81	0.790	8.988	0.230	7.057	0.181	11.13	0.286	5.633	0.144
66	**Yozgat**	2865	19	29.97	0.139	9.034	0.042	7.135	0.033	11.28	0.052	5.710	0.026
67	**Zonguldak**	1387	96	14.51	0.702	6.098	0.295	4.858	0.235	7.280	0.352	3.918	0.190
68	**Aksaray**	2200	192	23.01	1.405	7.567	0.462	5.948	0.363	9.244	0.564	4.787	0.292
69	**Bayburt**	3368	20	35.23	0.146	9.805	0.041	7.682	0.032	12.25	0.051	6.132	0.025
70	**Karaman**	2206	135	23.07	0.988	7.728	0.331	6.050	0.259	9.479	0.405	4.856	0.208
71	**Kırıkkale**	2102	226	21.99	1.653	7.229	0.543	5.765	0.433	9.032	0.679	4.627	0.348
72	**Batman**	1858	767	19.43	5.610	5.859	1.691	4.627	1.335	7.320	2.112	3.703	1.069
73	**Şırnak**	1171	1499	12.25	10.96	3.517	3.147	2.771	2.479	4.343	3.886	2.195	1.964
74	**Bartın**	1931	65	20.20	0.475	7.304	0.172	5.800	0.136	8.903	0.209	4.627	0.109
75	**Ardahan**	4585	1	47.96	0.008	11.41	0.002	8.950	0.001	14.45	0.002	7.118	0.001
76	**Iğdır**	2405	449	25.16	3.284	7.460	0.973	5.836	0.762	9.282	1.211	4.695	0.613
77	**Yalova**	1357	189	14.19	1.382	5.702	0.555	4.584	0.446	6.931	0.675	3.669	0.357
78	**Karabük**	2145	92	22.44	0.672	7.655	0.229	6.058	0.182	9.430	0.283	4.834	0.145
79	**Kilis**	1575	715	16.47	5.229	5.320	1.688	4.198	1.332	6.618	2.100	3.350	1.063
80	**Osmaniye**	929	733	9.722	5.360	3.585	1.977	2.835	1.564	4.390	2.421	2.284	1.260
81	**Düzce**	1629	108	17.04	0.790	6.554	0.304	5.224	0.242	8.101	0.375	4.224	0.196

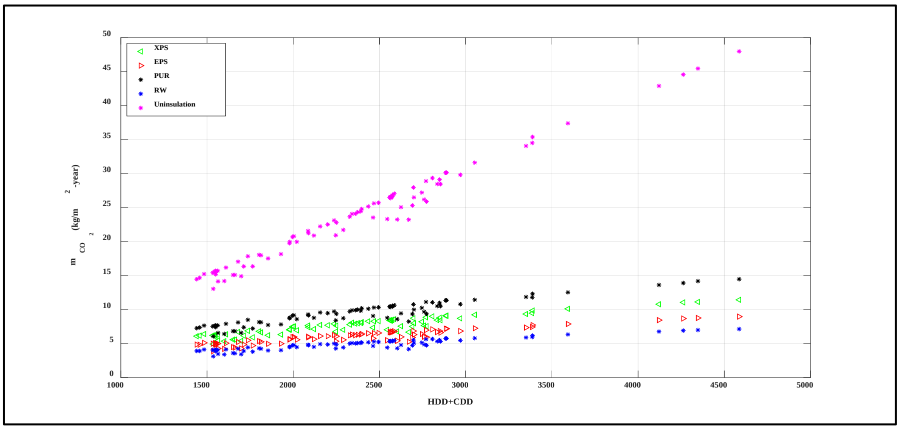

Figure 4. Variation of CO_2 emission values according to DD values and insulation materials.

4. Conclusion

In this study, firstly the optimum insulation thickness for thermal insulation to be applied to the outer walls of buildings in 81 city centers of Turkey was investigated by means of the life cycle cost analysis method for four different insulation materials commonly used in Turkey. Secondly, the amount of fuel based on energy savings stemming from the application of optimum insulation thickness was calculated. Thirdly, CO_2 emissions values of residential buildings were calculated from

energy sources including natural gas and electricity preferred for heating and cooling of the buildings, respectively. Therefore, results obtained from the present study can be summarized as follow:
1- It was observed that the insulation material thickness increased with respect to the increase in the number of Degree-Days.
2- The thinnest insulation material is found as PUR and as for the thickest insulation material, it is RW.
3- It has been determined that the buildings requiring the most energy based on their air conditioning needs are insulated with PUR material, while the buildings with the least energy need are those that are insulated with RW.
4- It was found that CO_2 emissions released from buildings showed an increase trend with increasing Degree-Day values.
5- When the CO_2 reduction potentials of the insulation materials are compared, they can be found as 78.85%, 73.65%, 66.66% and 58.89% for RW, EPS, XPS and PUR insulation materials, respectively.
6- When the annual heating and cooling needs of buildings in all cities of Turkey were evaluated together, it was determined that the total amount of CO_2 released from air conditioning of the unit area of the uninsulated external walls was approximately 1924.36 kg/m^2. However, this value decreases owing to the usage of thermal insulation materials as found in this study: it was found as 617.83, 487.68, 764.32 and 391.06 kg/m^2 in case of use of XPS, EPS, PUR and RW, respectively.
7- Based on all these findings listed above, it was determined that Rock Wool insulation material is less harmful to the environment and more economic and so correspondingly provides more energy efficient. Referring to these results, it was concluded that the use of RW as a thermal insulation material under Turkish conditions is more suitable than the other three (XPS, EPS and PUR) thermal insulation materials studied.

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