U-Value maps Turkey

Applying the comparative methodology framework for cost-optimality in the context of the EPBD

Final report

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Applying the comparative methodology framework for cost-optimality in the context of the EPBD

Final report

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Executive Summary

Turkey is the country with the fastest growing building stock on the European continent. With new construction rates of more than 4% it is considerably faster growing than the EU average of less than 1%. This leads to the fact that the construction sector is one of the most important drivers of the Turkish economy with a contribution of 6.6% of real GDP growth (Kaymaz, 2015). The building sector in Turkey (residential and services sectors) is responsible for about 35% of the national final energy consumption (EUROSTAT, 2016). Due to the significant new construction activities this share is expected to further increase in the future. The building stock is expected to grow by more than 50% from approximately 2,400 million m² today to almost 4,000 million m² in 2050. This fact makes clear that the Turkish building sector is one of the most important pillars for achieving Turkey's climate protection targets as defined in Turkey's "Intended Nationally Determined Contribution" (INDC) (Republic of Turkey, 2015) which has been submitted to the UNFCCC in 2015.

For limiting the national increase in energy consumption of Turkey's building sector, in 2008 the Turkish government has implemented its building code TS825 (TSI, 2008) which defines the calculation procedures for heating energy demand in buildings and which provides accompanying reference and permeable values. In this context, TS825 also defines minimum requirements on U-values for roof, façade, windows and ground plate of new buildings and buildings to be renovated. However, the regulation just contains rules for the heating energy demand, other energy related calculations e.g. for space cooling or auxiliary energy are not included in this mandatory standard for buildings in Turkey.

In the European Union (EU), the main legal instrument providing requirements and calculation procedures for limiting the energy demand of buildings is the Energy Performance of Buildings Directive (EPBD) (EU, 2010). There are two major concepts as regards the ambition level of energy performance requirements that were introduced with the recast EPBD and which have to be fulfilled by each EU Member State:

Cost-optimality
This is a life-cycle cost approach, including initial investment and operational cost (energy & maintenance) which needs to be applied by each EU Member State adjusted to national or regional circumstances for determining the minimum energy performance of building elements (e.g. U-values) and whole buildings (e.g. primary energy demand). The nationally required minimum energy performance needs to be set (based on assessment of reference buildings) at the level that results in the lowest life cycle costs.

Nearly zero-energy building (nZEB)
According to Article 2 EPBD, an nZEB is a building "that has a very high energy performance, the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources". From 2021 onwards, all new buildings in the EU are to be nearly zero-energy buildings. At the same time, the principle of cost-optimality is still valid. That means that ideally by 2021 nearly-zero energy buildings are cost-optimal. Therefore, in order to systematically

derive a reasonable ambition level and definition for nearly zero-energy buildings it makes sense to conduct cost-optimality calculations using (cost) assumptions that seem to be plausible for 2021 (or another year in which Turkey intends to introduce nearly zero-energy buildings).

In this study, the EPBD underlying EU regulation (EU) No 244/2012 on "establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements" (EC, 2012a) and its accompanying guidelines (EC, 2012b) is applied to Turkish market conditions with the aim to identify a possible gap between current requirements as defined by TS825 and the Turkish cost-optimal thermal building standards according to the EPBD's cost-optimality approach. In a second step, we have analysed whether these cost-optimal levels can already fulfil the greenhouse gas (GHG) emission reduction targets and if not, demonstrate a scenario which would lead to the envisaged amount of GHG emissions that needs to be mitigated. Such further strengthened energy requirements therefore could be a good starting point for the definition of a Turkish nearly zero-energy building standard.

For this purpose, Ecofys has developed a cost-optimality tool according to the requirements as defined in the Commission Delegated Regulation (244/2012) regarding the energy performance of buildings. The model calculates cost-optimal building configurations (considering both demand and supply side) for different reference buildings under varying climatic conditions. The model can be adopted to local conditions. With regard to physical issues, local construction practices as well as climatic circumstances are taken into consideration for instance, in order to calculate hourly heating and cooling demands as specified by EU norm EN ISO 13790. Local hourly climate data sets are exported from METEONORM. The calculated heating and cooling demands feed into the calculation of global costs, along with micro- and macroeconomic parameters such as dynamic costs for building components and variable energy prices. The model calculates thousands of combinations of U-values, heating and cooling systems and identifies the technical configuration which yields the lowest global costs over the calculation period (30 years for residential buildings according to the EPBD's cost-optimality approach). A private or societal perspective can be adopted for defining cost-optimality. As well, the calculation model can be applied to both new and renovated buildings and is able to include typical local reference buildings and geometries. Based on the 2011 and 2001 census results, it has been decided to use a 5 story multi-family house as reference building for the calculations as it is most present in the Turkish especially urban building stock and therefore most relevant for this analysis. For calculating the energy saving potential and identifying the U-values that are needed in order to reach climate protection targets as defined in Turkey's INDC, the results on reference building level have been extrapolated to the entire building stock and its modelled future development until 2050.

Due to the quite heterogeneous climate in Turkey and in order to allow a more appropriate extrapolation of derived results for a limited number of cities to the whole Turkish building stock, the four climate regions as defined in TS825 have been restructured into 6 new climate regions according to the following table:

Region	Climate classification	HDDs (acc. to ASHRAE)	CDDs (acc. to ASHRAE)	Number of Turkish provinces in class	Climate region according to TS825
1	Hot	<1000	>1000	4	1
2	Cooling-based	1000-2000	>=1000	10	1-2
3	Moderate	<2000	<1000	17	2
4	Rather cold	>=2000	<1000	32	3
5	Medium cold	>=3000	<1000	13	4
6	Cold	>=4000	<1000	5	4

These six regions allow a more detailed analysis of recommendable U-values based on different climate conditions and therefore have been used for all tasks of this study.

The following figures show the calculation results of cost-optimal U-values according to EPBD's cost-optimality procedure and U-values for reaching climate protection targets according to the national INDC for both new and existing buildings undergoing a major renovation. Turkey's INDC defines a climate protection target of reducing Turkey's greenhouse gas emissions by up to 21% from the Business as Usual (BAU) level by 2030. The figures also provide a comparison with current requirements according to TS825.

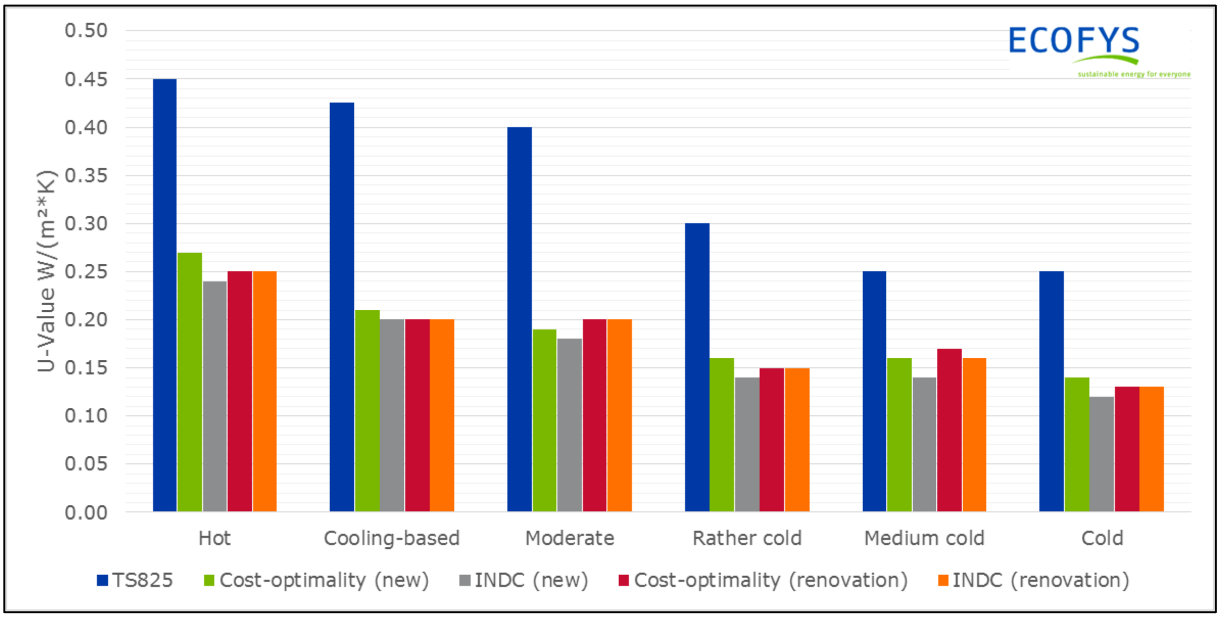

Figure 1. U-value results for roofs in new and existing buildings undergoing a major renovation according to cost-optimality and achievement of climate targets as defined in Turkey's INDC for all six climate regions as used in this report

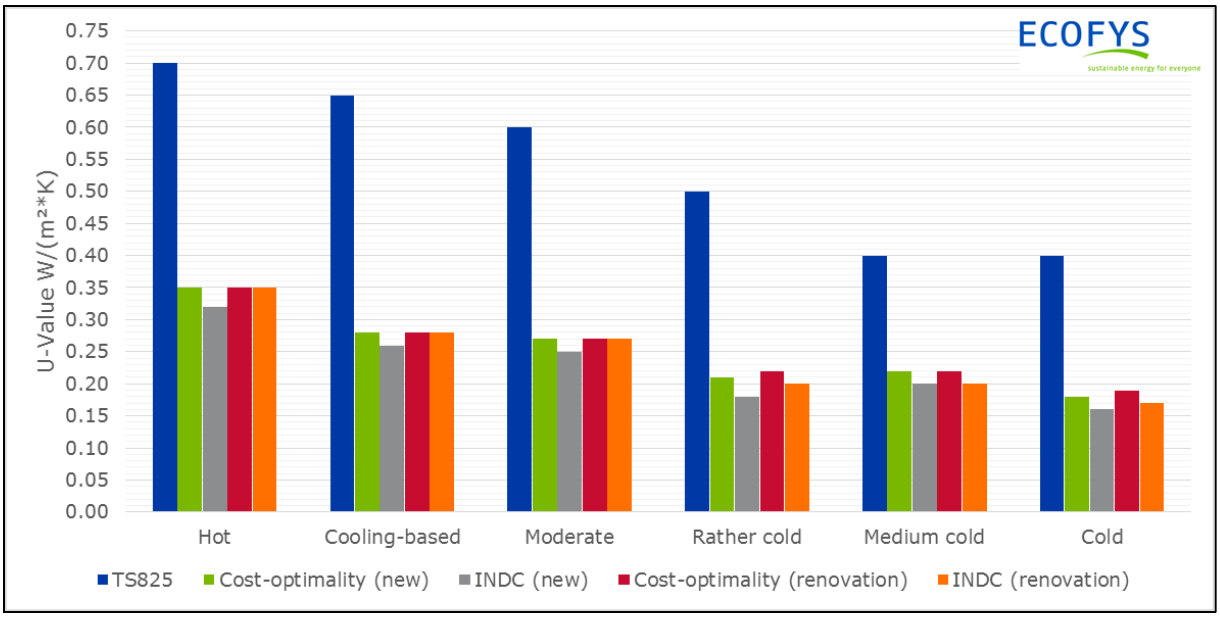

Figure 2. U-value results for façades in new and existing buildings undergoing a major renovation according to cost-optimality and achievement of climate targets as defined in Turkey INDC for all six climate regions as used in this report

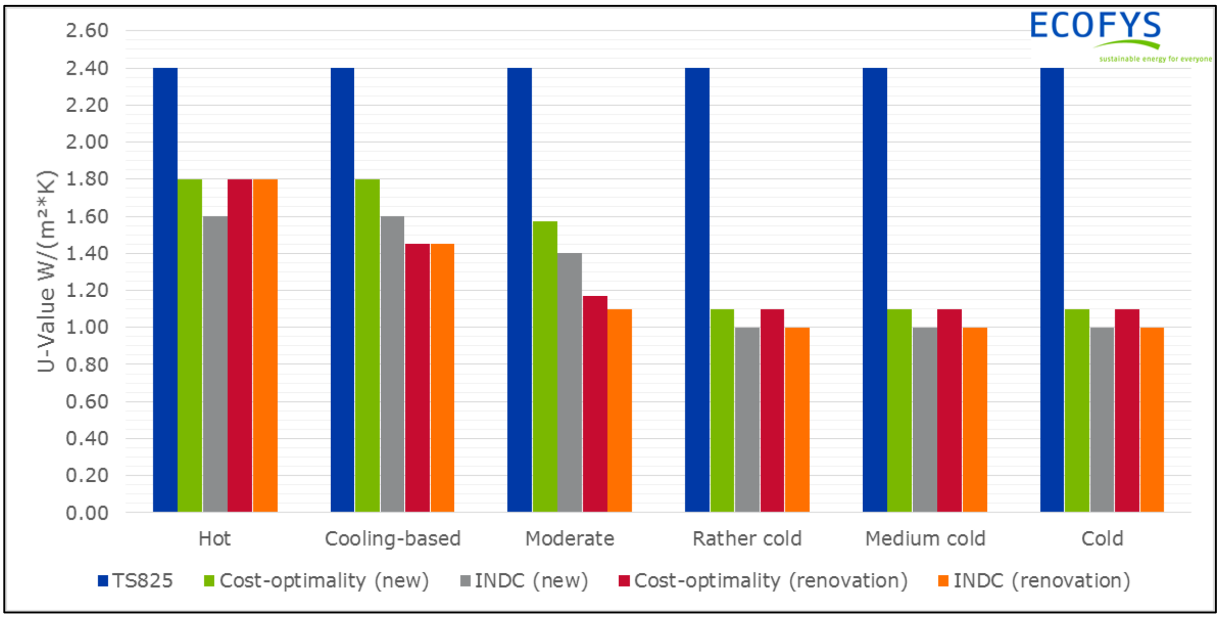

Figure 3. U-value results for windows in new and existing buildings undergoing a major renovation according to cost-optimality and achievement of climate targets as defined in Turkey INDC for all six climate regions as used in this report

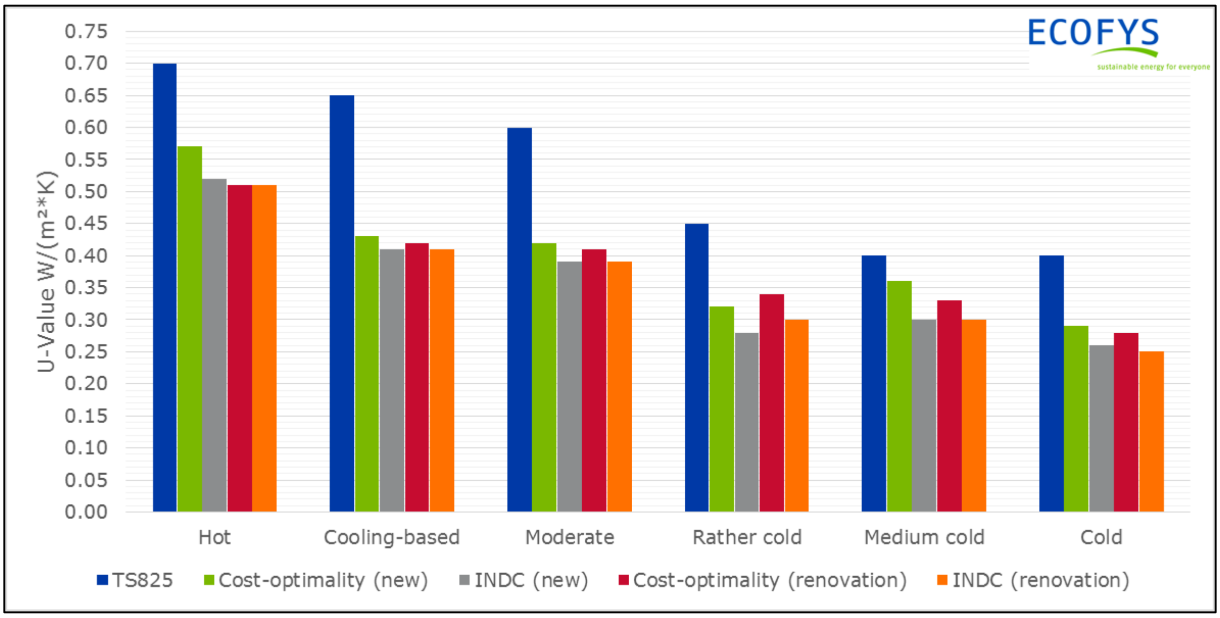

Figure 4. U-value results for ground plates in new and existing buildings undergoing a major renovation according to cost-optimality and achievement of climate targets as defined in Turkey INDC for all six climate regions as used in this report

Based on the identified U-values, the following primary energy demands for space heating and space cooling result.

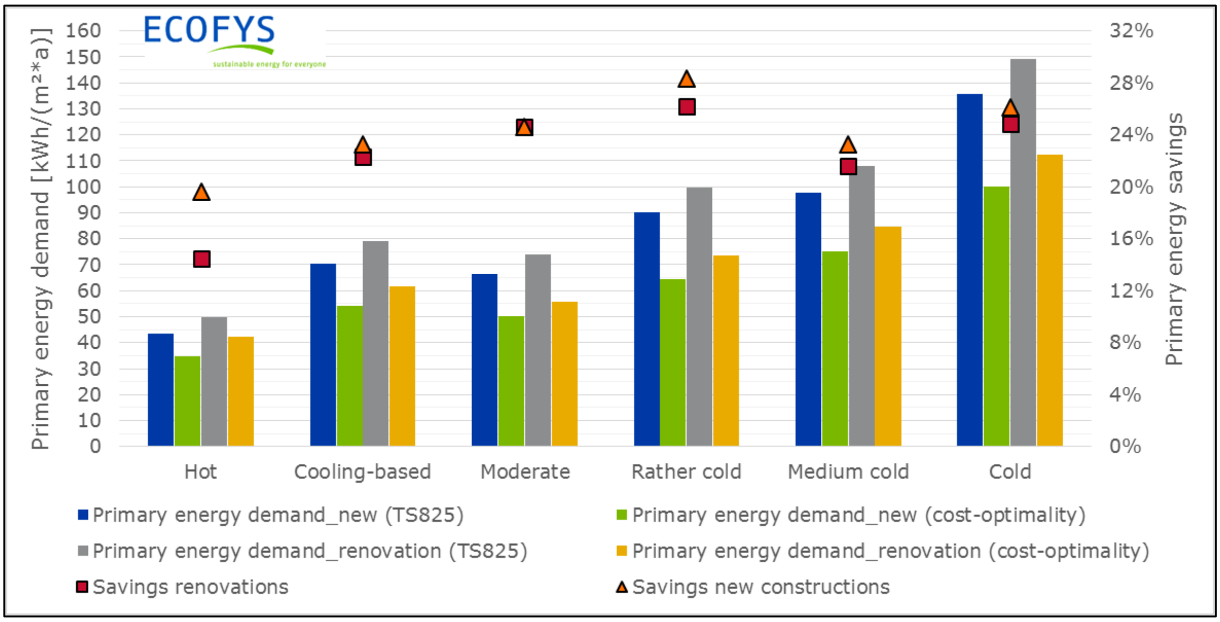

Figure 5. Primary energy demands of new and existing buildings undergoing a major renovation according to the current building code TS825 and cost-optimality calculations for all six climate regions as used in this report

By applying the new standards, the following figure presents the potentials for final energy savings until 2023, 2030, 2040 and 2050.

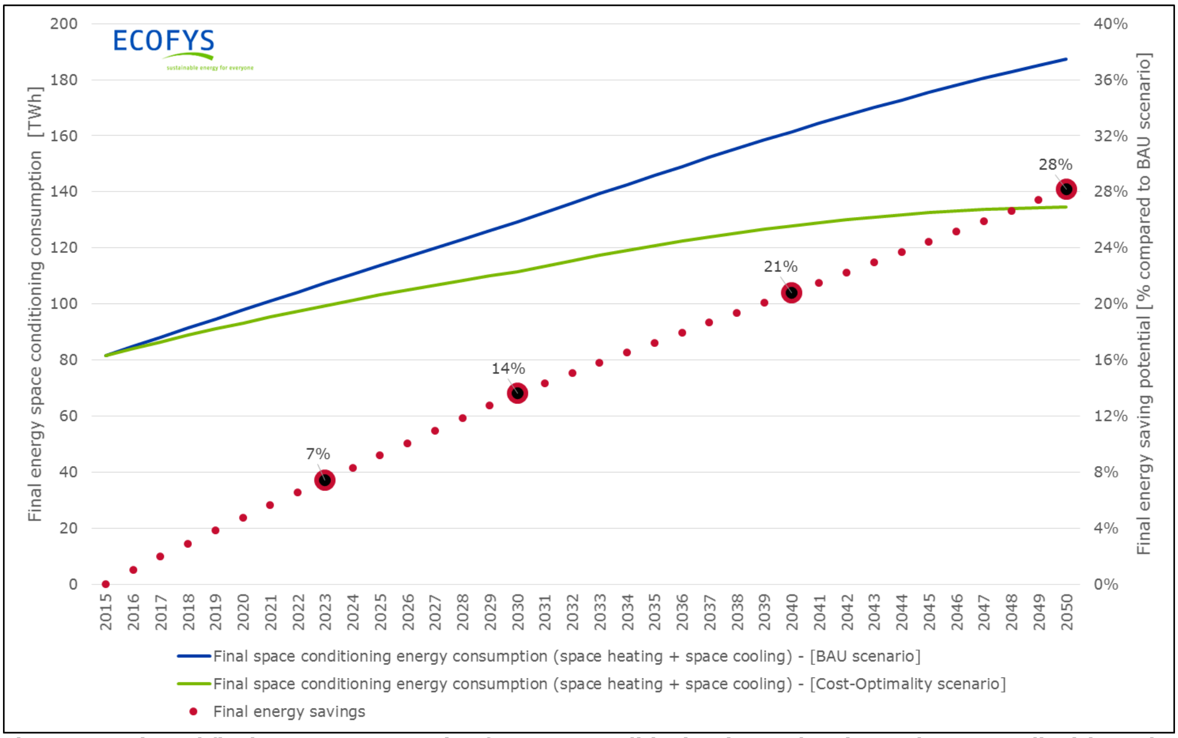

Figure 6. Projected final energy consumption for space conditioning (space heating and space cooling) in Turkey's residential building sector 2015-2050 in the BAU and the cost-opt scenarios and the resulting final energy savings in the cost-opt scenario compared to the BAU scenario

As can be seen, by increasing the U-value requirements to cost-optimal levels, until 2023 about 7% final energy can be saved, by 2030 about 14% and until 2050, about 28%. As the implementation of the cost-optimality standards leads to final energy savings of approximately 14% in 2030 and by using IPCC standard emission factors for fossil fuels and an emission factor of 0.55 kg CO_{2e}/kWh for electricity and assuming that the emission factors keep stable until 2030, this energy saving potential correlates with an emission reduction potential of ~12% until 2030.

In order to close the remaining gap of ~9% to reach the targeted 21% emission reduction as defined in the INDC, with a focus on energy efficiency measures on the demand side, a combination of increased renovation rate and further improved U-values is necessary. As a possible solution, today's renovation rate from 0.45% (Elsland et al., 2014) should be increased to 1% and furthermore increased linearly to 2% in 2030. This correlates with an average renovation rate of 1.5% in the period 2015-2030. Additionally the calculated cost-optimality U-values need to be further strengthened, on average by 11% for new buildings and by 10% for existing buildings to be refurbished (see figures 1-4). In addition, the heat/cold bridge factors need be reduced from currently about 0.1 W/(m²*K) in new buildings and 0.15 W/(m²*K) in existing buildings to 0.05 W/(m²*K) and 0.1 W/(m²*K) respectively. In warm regions, this improvement of the heat bridge factor can already be sufficient for achieving the needed emission reduction.

The following figure illustrates the building stock and emission development until 2030, in case that the more ambitious U-values are applied and the renovation rate is being increased.

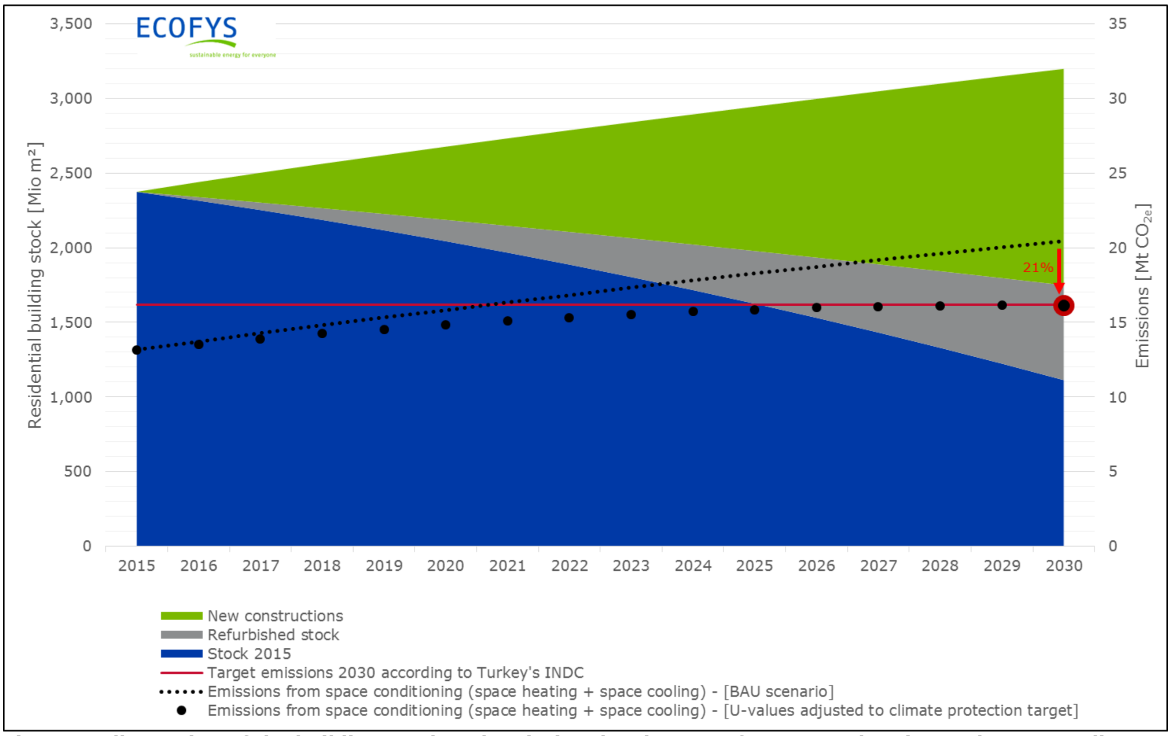

Figure 7. Illustration of the building stock and emission development from space heating and space cooling assuming an increase of the renovation rate from 1% in 2015 to 2% in 2030 and 11% more ambitious U-values for new constructions and 10% for renovations compared to CO-levels

Based on the above, the following conclusions can be drawn:

- The U-values as derived from the cost optimality methodology are suitable to support reaching 2030 climate protection targets. This means that climate protection and cost-optimality are not contradictory but can be well combined.
- Reaching climate targets requires further strengthening of the U-values by ~10% towards 2030 compared to today's cost-optimality levels (needed 2030 values are likely to be cost-optimal as well, if energy prices further raise)
- For the improvement of U-values from TS825 standard to cost-optimal U-values would require additional investment costs of 3-10€ per m² building floor area, in average ~6.5€.
- Recommended maximum U-values resulting from the analyses based on cost-optimality and fitting climate protection targets are significantly more ambitious than current requirements according to TS825, offering room for strengthening of requirements.
- For reaching climate targets, U-value requirements should be strengthened rather sooner than later to avoid lock-in effects or capital intense upgrades of building envelopes before the end of their technical life-time.
- In residential buildings in warmer parts of Turkey, thermal insulation also reduces the energy demand for cooling. A well balanced package of roof, wall and floor insulation and selection of the right window with suitable U-values as well as g-values results in a significant and cost-effective reduction of energy demand for space heating and cooling.

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1 Introduction

Turkey is the country with the fastest growing building stock on the European continent and with almost 80 million inhabitants the third largest after Russia and Germany. With new construction rates of more than 4% it is considerably faster growing than the EU average of less than 1%. This leads to the fact that the construction sector is one of the most important drivers of the Turkish economy with a contribution of 6.6% of real GDP growth (Kaymaz, 2015). The building sector in Turkey (residential and services sectors) is responsible for about 35% of the national final energy consumption (EUROSTAT, 2016). Due to the significant new construction activities this share is expected to further increase in the future. The building stock is expected to grow by more than 50% from today approximately 2,400 million m² to almost 4,000 million m² in 2050. This fact makes clear that the Turkish building sector is one of the most important pillars for achieving Turkey's climate protection targets as defined in Turkey's "Intended Nationally Determined Contribution" (INDC) (Republic of Turkey, 2015) which has officially been submitted to the UNFCCC on September 30th 2015.

For limiting the national increase in energy consumption of Turkey's building sector and thus reduce Turkey's significant dependency from energy imports, in 2008 the Turkish government has implemented its building code TS825 (TSI, 2008) which defines the calculation procedures for heating energy demand in buildings and which provides accompanying reference and permeable values. In this context, TS825 also defines minimum requirements on U-values for roof, façade, windows and ground plate of new buildings and buildings to be renovated. However, the regulation just contains rules for the heating energy demand, other energy related calculations including cooling are not included in this mandatory standard for buildings in Turkey.

In the European Union (EU), the main legal instrument providing requirements and calculation procedures for limiting the energy demand of buildings is the Energy Performance of Buildings Directive (EPBD) (EU, 2010). The EPBD first came into force 16 December 2002 with the aim to improve the overall energy performance of new buildings and large existing buildings in the event of a major renovation. Because the building sector being responsible for about 40% of Europe's total energy consumption, the EPBD is an important step for the European Union to reach its climate targets. In 2010 the EPBD was recast and the two new major concepts regarding the ambition level of energy performance requirements that were introduced and which have to be fulfilled by each EU Member State are cost-optimality and nearly zero-energy buildings.

Cost-optimality

This is a life-cycle cost approach, including initial investment and operational cost (energy & maintenance) which needs to be applied by each EU Member State adjusted to national or regional circumstances for determining the minimum energy performance of building elements (e.g. U-values) and whole buildings (e.g. primary energy demand). The nationally required minimum energy performance needs to be set (based on assessment of reference buildings) at the level that results in the lowest life cycle costs.

Nearly zero-energy building (nZEB)

According to Article 2 EPBD, an nZEB is a building "that has a very high energy performance, the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources". From 2021 onwards, all new buildings in the EU are to be nearly zero-energy buildings. At the same time, the principle of cost-optimality is still valid. That means that ideally by 2021 nearly-zero energy buildings are cost-optimal. Therefore, in order to systematically derive a reasonable ambition level and definition for nearly zero-energy buildings it makes sense to conduct cost-optimality calculations using (cost) assumptions that seem to be plausible for 2021 (or another year in which Turkey intends to introduce nearly zero-energy buildings).

For supporting the insulation industry in Turkey to take a clear and well-founded position on future standards, Ecofys has been contacted by IZODER to apply the comparative methodology framework for cost-optimality in the context of the EPBD to the Turkish residential building sector with the aim to investigate cost-optimal U-values and assess their potential role in achieving Turkey's climate protection targets. Part of the project should also be to create GIS[1]-based U-value maps for Turkey in the style of ECOFYS' 2007 U-value maps report for EURIMA (Boermans & Petersdorff, 2007) but methodologically adjusted to the cost-optimality principle of the EPBD recast. The analysis has been conducted for the 12 Turkish cities Antalya, İzmir, Gaziantep, Muğla, İstanbul, Bursa, Ankara, Niğde, Sivas, Ağrı, Kars and Erzurum by using city specific calculation parameters and hourly climate data. Based on this limited number of cities it should be noted that results that have been extrapolated to regional scale (e.g. climate regions) are not necessarily 100% representative for the whole region but provide a sound based first indication.

[1] Geo Information System. Maps have been created with ArcGIS

2 Background

This chapter provides some background information about the Turkish building code and its climate specifications.

2.1 Turkish building code

In 2008, the Turkish government has implemented its building code TS825 (TSI, 2008) which defines the calculation procedures for heating energy demand in buildings and which provides accompanying reference and permeable values. In this context, TS825 also defines minimum requirements on U-values for roof, façade, windows and ground plate of new buildings and buildings to be renovated. However, the regulation just contains rules for the heating energy demand, other energy related calculations e.g. for space cooling or auxiliary energy are not included in this mandatory standard for buildings in Turkey.

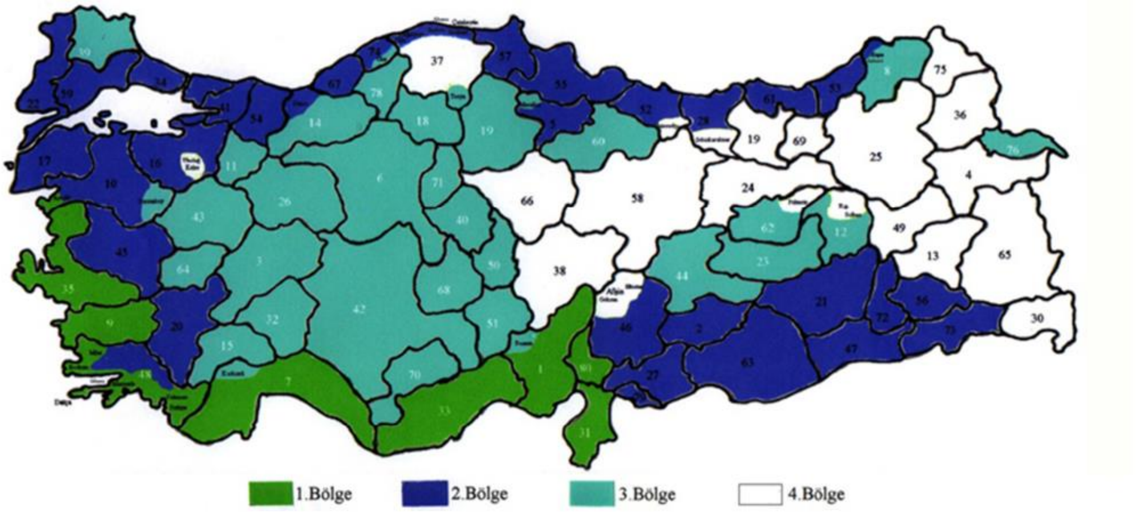
Esiyok (2006) describes that "the Turkish State Meteorological Service and TSE (Turkish Standards Institution) classified Turkish climate regions as "Thermal Insulation Regions" by using a degree-day method which was developed by the Turkish State Meteorological Service. The classification, the number of temperature over 10 °C which is derived from 236 stations between 1981 and 2001, has been calculated as follows:

*Effective Total Temperature (Degree Days) = (M-10) * N*

M: Monthly mean temperature,

N: Number of days in the month

Degree days for all cities and some towns are listed by using monthly mean temperatures in the equation. Degree days are not classified as heating and cooling degree days like it was mentioned in the ASHRAE classification. According to this classification Turkey is divided into four insulation regions: this was used for the Turkish Standard 825 (thermal insulation in buildings) to determine consumption values and insulation requirements". Figure 8 presents the location of these four climate (insulation) regions and how they are distributed over Turkey.



01- ADANA	10- BALIKESİR	19- ÇORUM	28- GİRESUN	37- KASTAMONU	46- K.MARAŞ	55- SAMSUN	64- UŞAK	73- ŞIRNAK
02- ADIYAMAN	11- BİLECİK	20- DENİZLİ	29- GÜMÜŞHANE	38- KAYSERİ	47- MARDİN	56- SİİRT	65- VAN	74- BARTIN
03- AFYON	12- BİNGÖL	21- DİYARBAKIR	30- HAKKARİ	39- KIRKLARELİ	48- MUĞLA	57- SİNOP	66- YOZGAT	75- ARDAHAN
04- AĞRI	13- BİTLİS	22- EDİRNE	31- HATAY	40- KIRŞEHİR	49- MUŞ	58- SİVAS	67- ZONGULDAK	76- IĞDIR
05- AMASYA	14- BOLU	23- ELAZIĞ	32- ISPARTA	41- KOCAELİ	50- NEVSEHİR	59- TEKİRDAĞ	68- AKSARAY	77- YALOVA
06- ANKARA	15- BURDUR	24- ERZİNCAN	33- İÇEL	42- KONYA	51- NİĞDE	60- TOKAT	69- BAYBURT	78- KARABÜK
07- ANTALYA	16- BURSA	25- ERZURUM	34- İSTANBUL	43- KÜTAHYA	52- ORDU	61- TRABZON	70- KARAMAN	79- KİLİS
08- ARTVİN	17- ÇANAKKALE	26- ESKİŞEHİR	35- İZMİR	44- MALATYA	53- RİZE	62- TUNCELİ	71- KIRIKKALE	80- OSMANİYE
09- AYDIN	18- ÇANKIRI	27- GAZİANTEP	36- KARS	45- MANİSA	54- SAKARYA	63- ŞANLIURFA	72- BATMAN	81- DÜZCE

Figure 8. Climate regions according to the Turkish building code TS825

The U-value requirements for each region are presented in the following table.

Table 1. U-value requirements according to TS825

TS825 climate region	Wall [W/(m²*K)]	Roof [W/(m²*K)]	Floor [W/(m²*K)]	Window [W/(m²*K)]
1	0,7	0,45	0,7	2,4
2	0,6	0,4	0,6	2,4
3	0,5	0,3	0,45	2,4
4	0,4	0,25	0,4	2,4

A visualisation of these U-value requirements according to TS825 for the four considered building elements wall, roof, floor and windows are presented in the following figures.

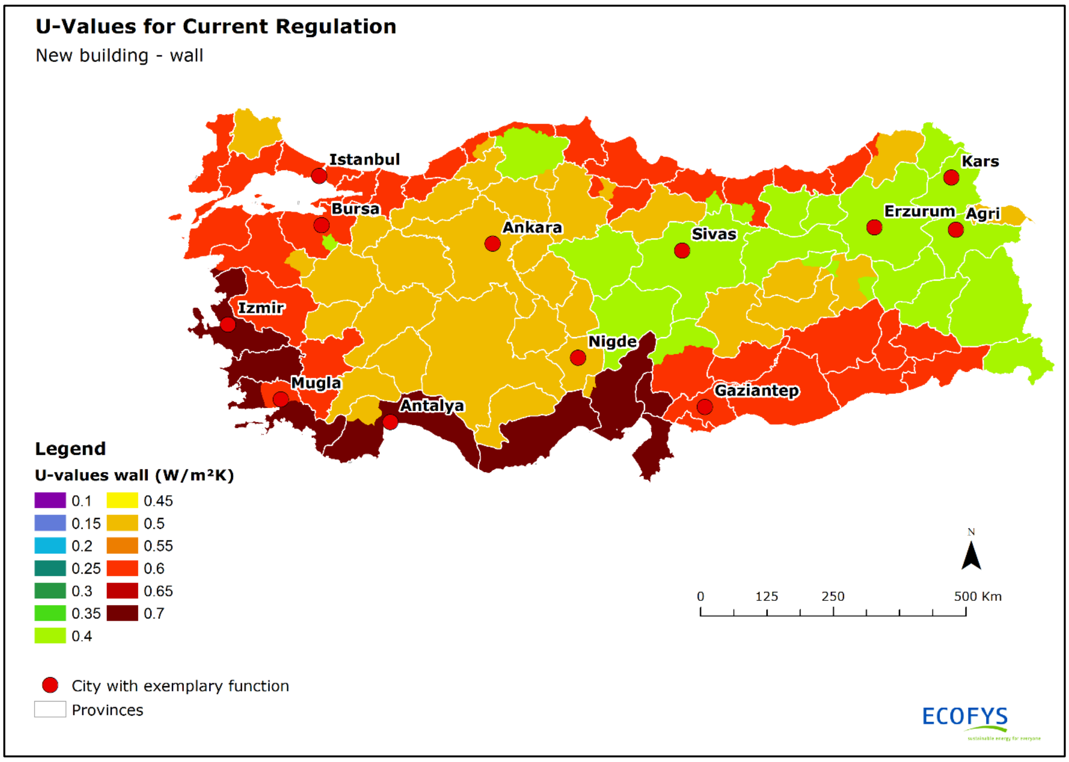


Figure 9. U-value requirements for walls according to TS825

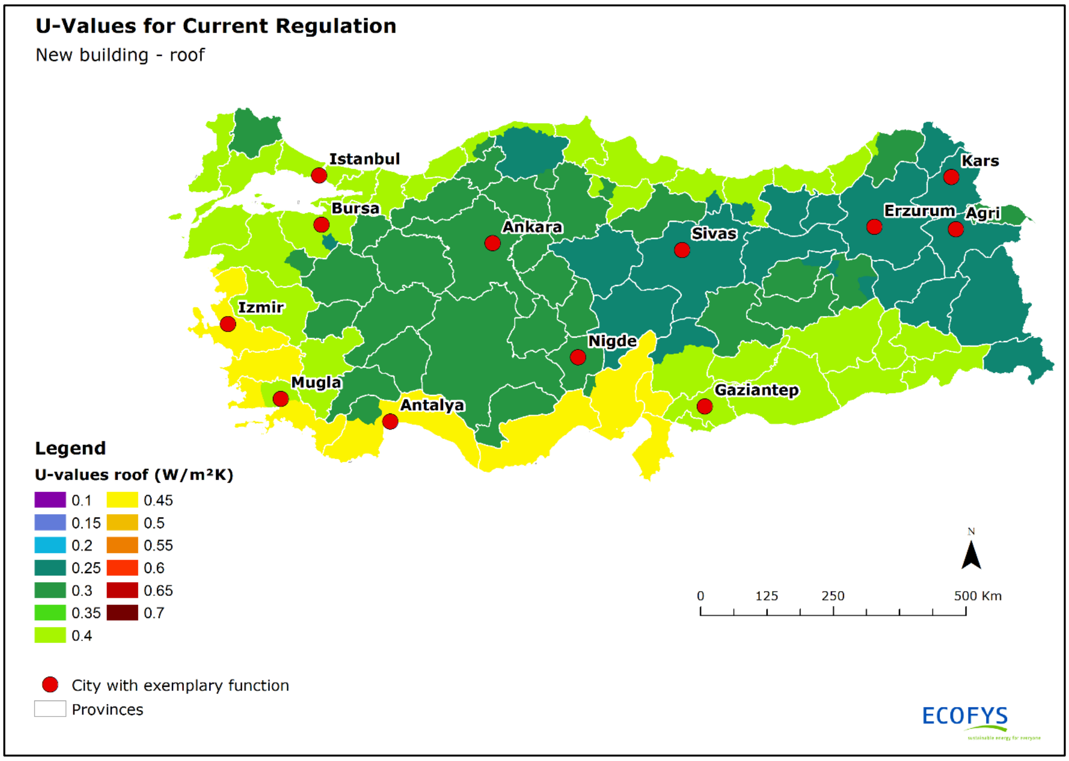


Figure 10. U-value requirements for roofs according to TS825

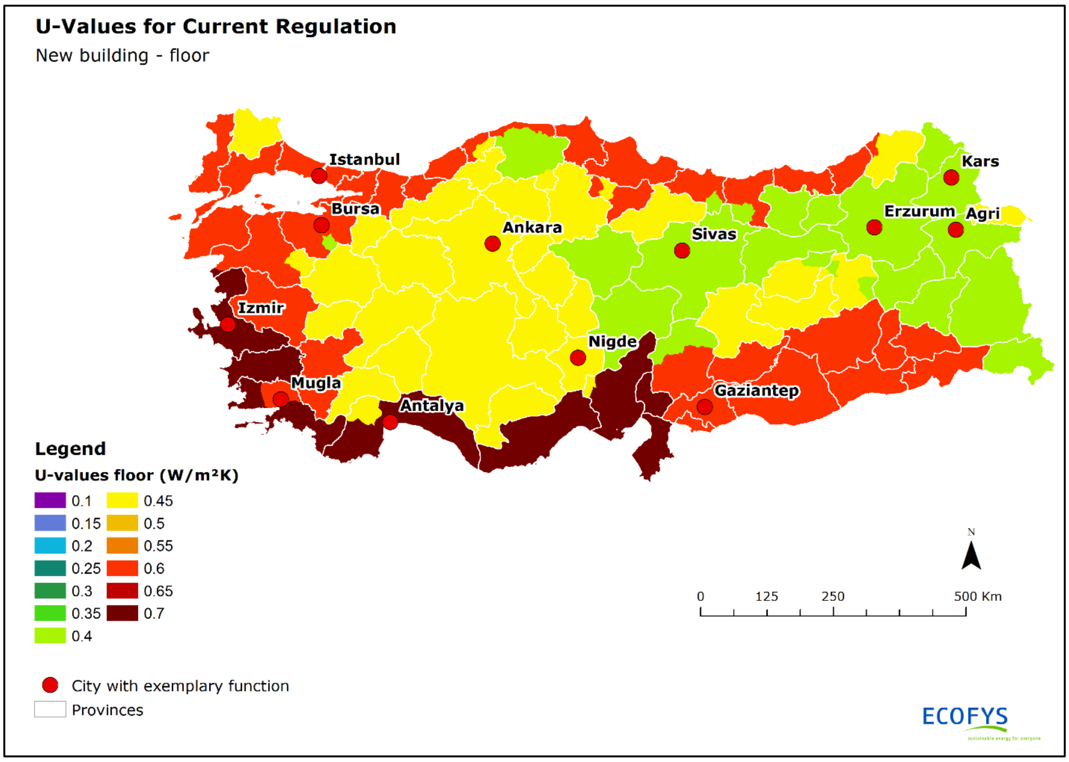


Figure 11. U-value requirements for floors according to TS825

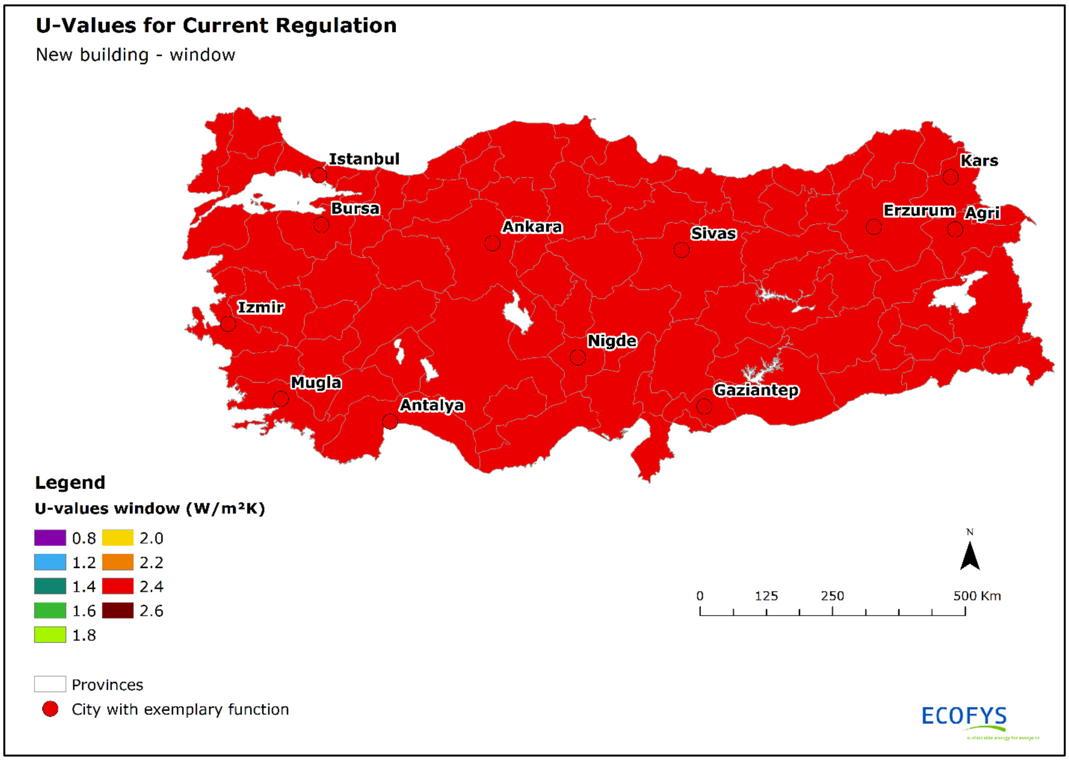


Figure 12. U-value requirements for windows according to TS825

2.2 Turkish geographical characteristics and climate

Turkey is one of the largest countries in Europe and Middle East with its 779452 km² total area (23764 km² on the European side, 755688 km² on the Asian side). The country lies between 36-42 north latitude and 26-45 east longitude and situated between two continents - Europe and Asia (Esiyok, 2006).

It is surrounded by three seas with a total of 8372 km total coastline. The country has seven geographical regions: Marmara, Aegean, Mediterranean, Southeast Anatolia, East Anatolia, Black Sea and Central Anatolia. The neighbouring countries are Greece and Bulgaria to the northwest, Armenia and Georgia to the northeast, Iraq and Iran to the southeast and Syria to the south. The highest mountain in Turkey is Mount Ararat (5165 m) and biggest lake is Lake Van: both are located in eastern Anatolia. A topographic map of Turkey is presented in Figure 13 (Esiyok, 2006).

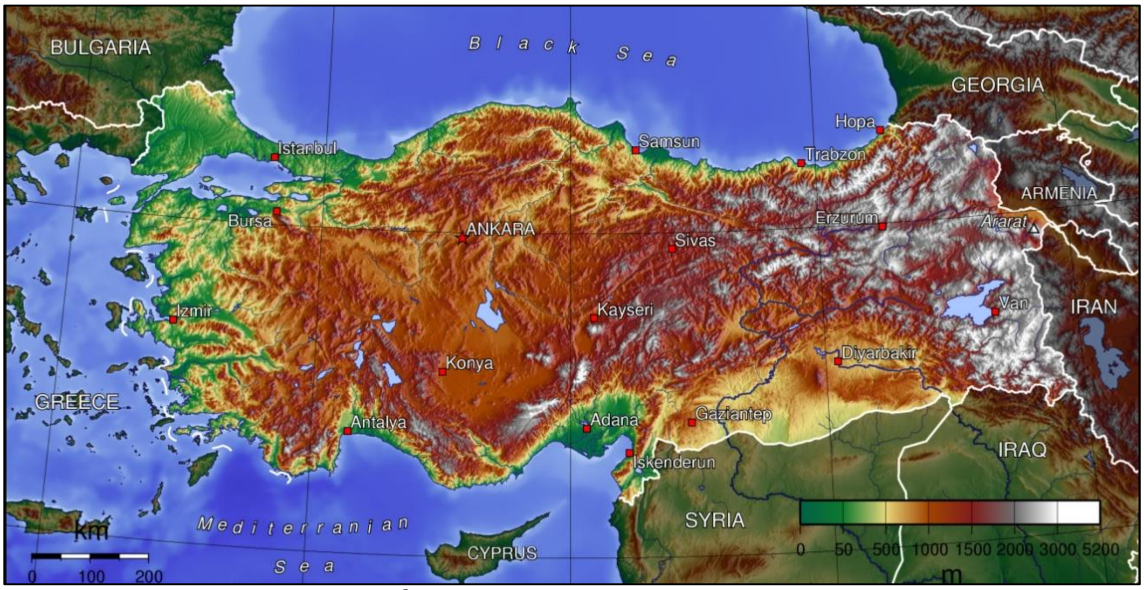


Figure 13. Topographic map of Turkey[2]

According to the Köppen Classification, Turkey is situated in the temperate Mediterranean climatic and geographical zone. The country has three main climatic zones: the Black Sea region is mild and generally rainy throughout the year with the temperature neither very low in winter nor very high in summer. The southern and western coastlines have a typical Mediterranean climate with mild winters and hot, dry summers. The Interior parts of Anatolia, with high land plains and a mountainous region east of Anatolia are marked by cold and snowy winters, hot and dry summers (Esiyok, 2006).

Although the country has three main climate zones, the climate shows different characteristics and can be grouped into five climate groups (Burak, 2002) because of their different geographical

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[2] http://www.jdemirdjian.com/images/Turkey_topo1.jpg

characteristics. For example in the Mediterranean region, mountains (Taurus Mountains) run parallel to the coasts and prevent the clouds from passing over into the interior parts of the country therefore the coastal side of the region receives more rainfall than the other part of the region. As a result Turkey shows both continental climate and subtropical climate characteristics (Esiyok, 2006).

The following three figures show the geographical distribution of annual temperatures, solar irradiation and climate classification of Turkey via Thornthwaite method (Sensoy, 2016).

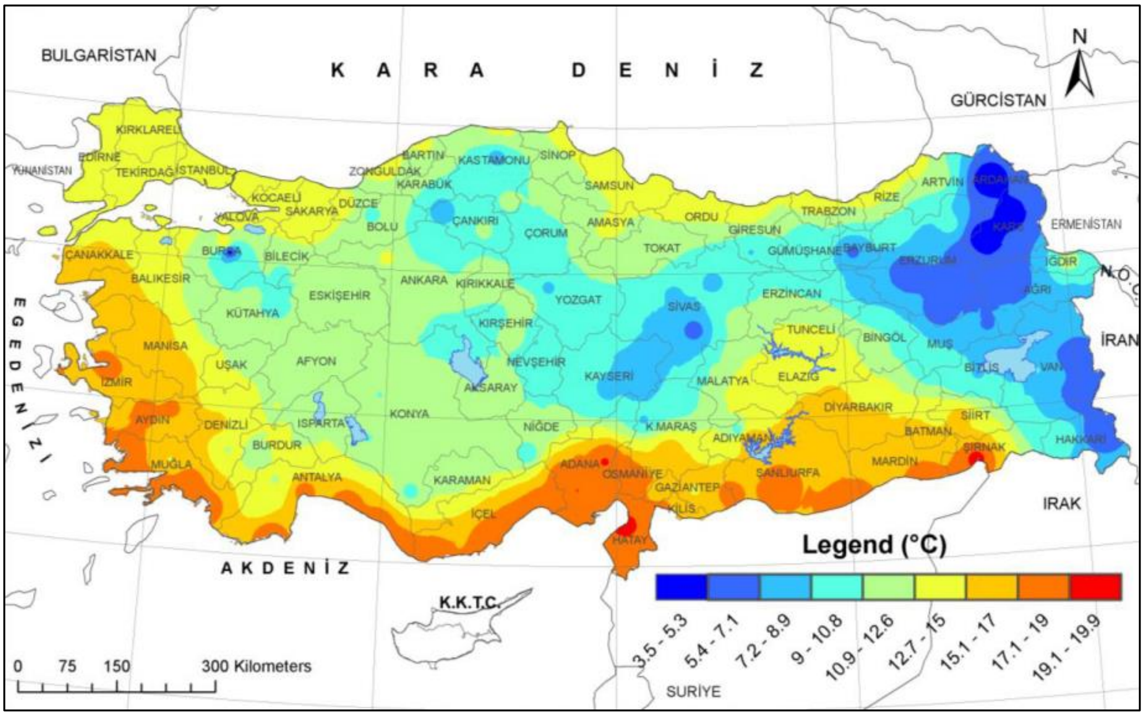

Figure 14. Geographical distribution of mean annual temperature (Sensoy, 2016)

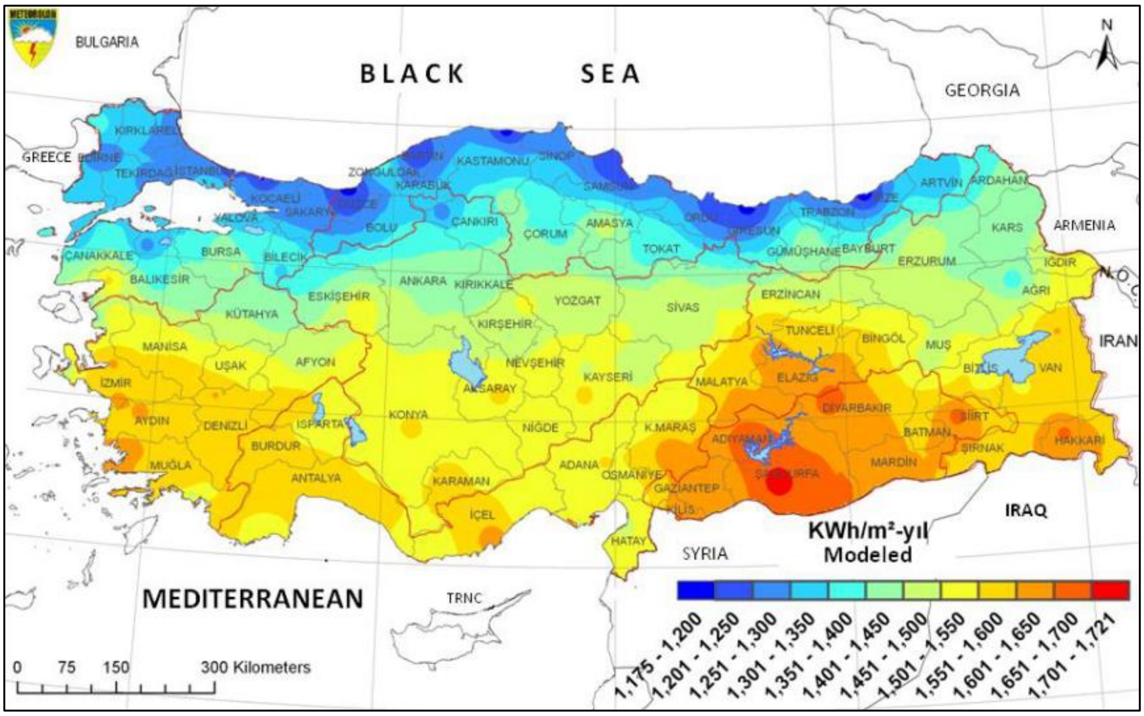

Figure 15. Modeled average total solar irradiation distribution over Turkey (Sensoy, 2016)

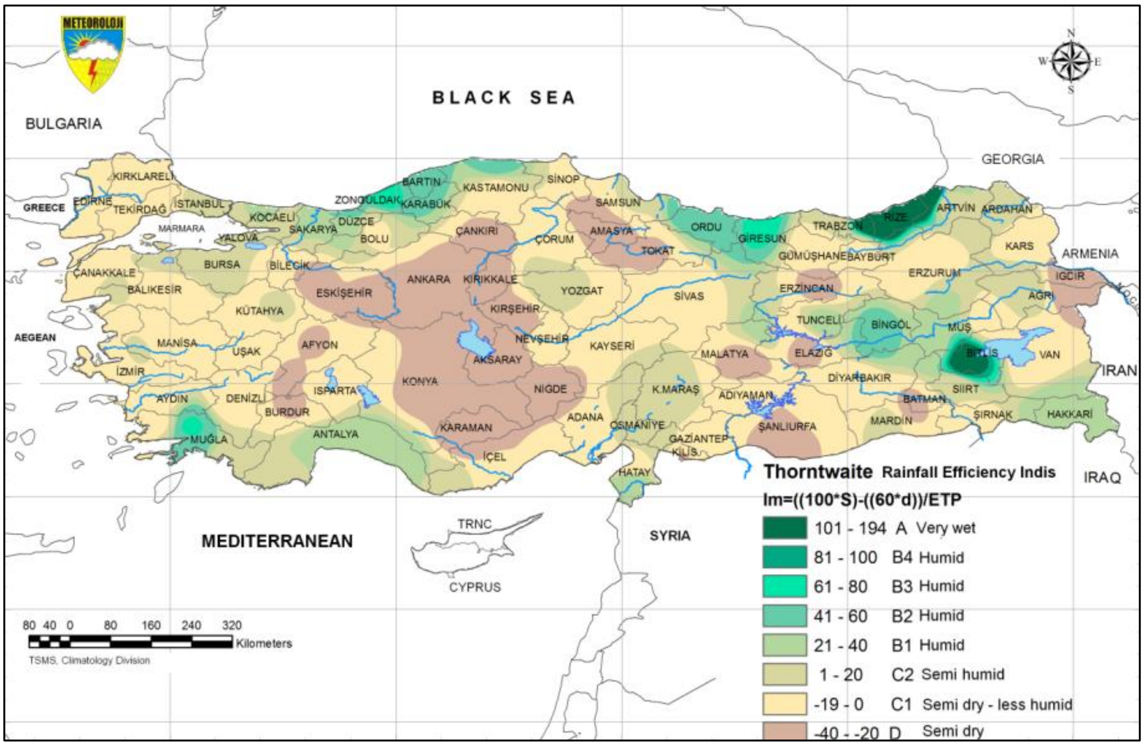

Figure 16. Climate classification of Turkey via Thornthwaite method (Sensoy, 2016)

2.3 Turkish heating and cooling degree days maps and new climate regions

Heating and cooling degree days express the severity of the cold and the heat over a specific time period taking into consideration outdoor temperature and room temperature. For calculating degree days of the 81 Turkish cities, hourly weather data was taken from METEONORM and used to calculate heating and cooling degree days (HDD and CDD) using the methodology applied by ASHRAE, which forms a common and comparable basis. External and internal building conditions may require additional energy for cooling and ventilation in order to meet a defined comfort level. This comfort level may be defined in building regulations or be given as user specifications.

The following two figures present the heating and cooling degree day maps for Turkey. They are based on own calculations according to the methodology as described in ANNEX 1. The results of the heating and cooling degree days calculations can also be found in ANNEX 1. It should be noted that the degree days have been calculated for the province capitals and considered as representative for the whole province. Therefore, the degree days of the provinces cannot fully represent all regional details and differences within a province.

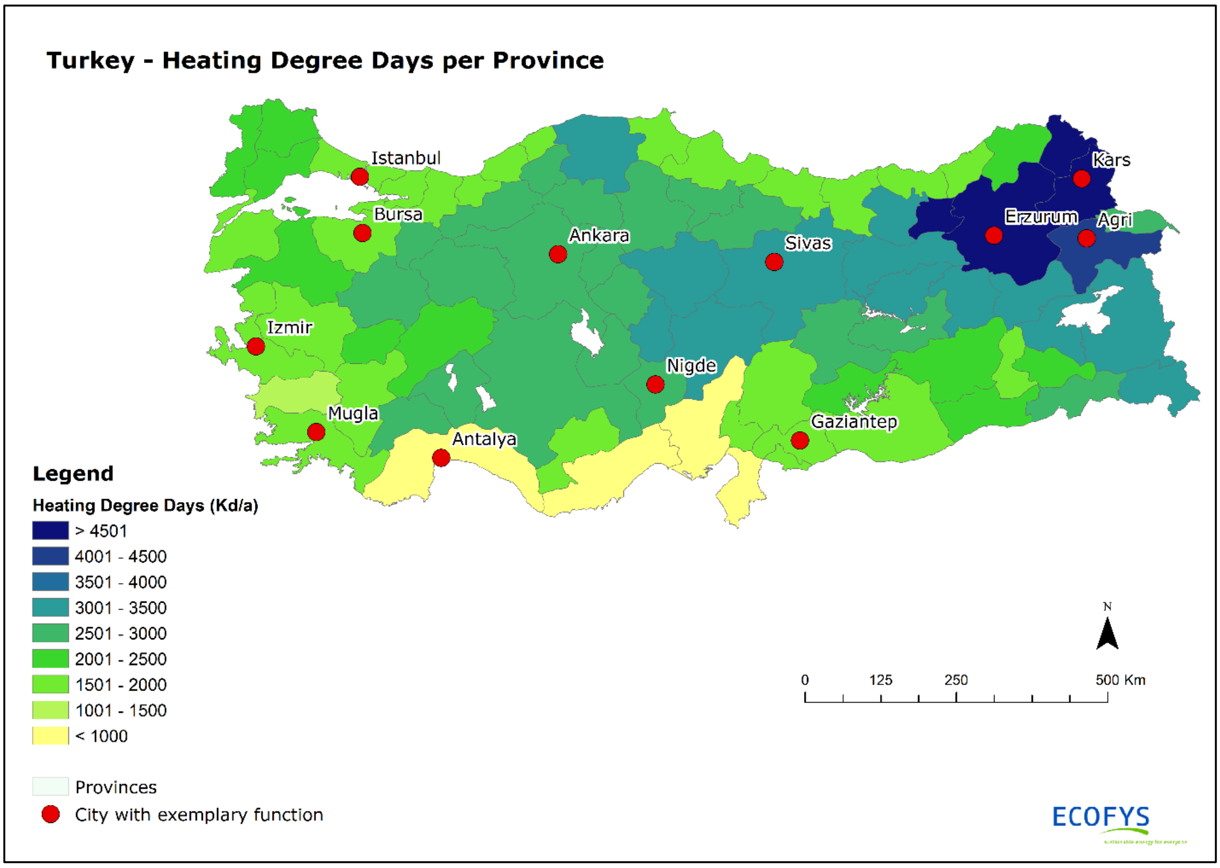

Figure 17. Turkish heating degree days map (ASHRAE method)

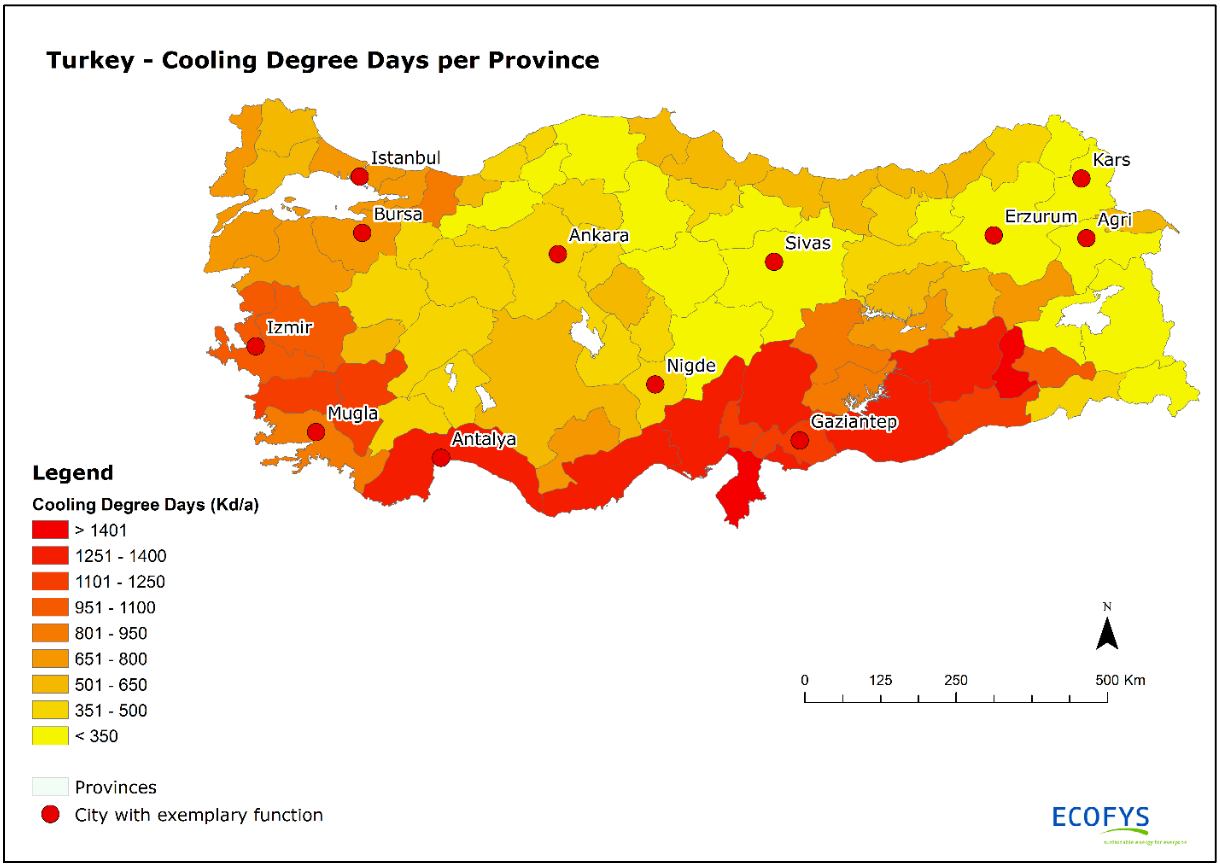

Figure 18. Turkish cooling degree days map (ASHRAE method)

As can be seen in the figures above, the climate in Turkey differs significantly from province to province. Based on the 12 covered cities we therefore developed a methodology which allows to further analyse differences in terms of U-values. We defined six climate regions whose characteristics in terms of heating and cooling degree day ranges are presented in the following table.

Table 2. Characteristics of the six developed climate regions as used in this study

Region	Climate classification	HDDs (acc. to ASHRAE)	CDDs (acc. to ASHRAE)	Number of Turkish provinces in class	Number of covered cities in region	Name of covered city	Climate region according to TS825
1	Hot	<1000	>1000	4	1	Antalya	1
2	Cooling-based	1000-2000	>=1000	10	2	Gaziantep, İzmir	1-2
3	Moderate	<2000	<1000	17	3	Bursa, İstanbul, Muğla	2
4	Rather cold	>=2000	<1000	32	2	Ankara, Niğde	3
5	Medium cold	>=3000	<1000	13	1	Sivas	4
6	Cold	>=4000	<1000	5	3	Ağrı, Erzurum, Kars	4

3 U-values according to cost-optimality

3.1 Methodology

In 2012, the European Union has issued a Commission Delegated Regulation (244/2012) regarding the energy performance of buildings. It establishes a comparative methodology to calculate cost-optimal levels of the optimized energy performance of buildings and building elements. Based on the calculations of primary energy use and global costs associated with different measures / packages / variants assessed for the defined reference buildings, graphs can be drawn per reference building that describe primary energy use (x-axis: kWh primary energy/(m² useful floor area and year)) and global costs (y-axis: EURO/m² useful floor area) of the different solutions. From the number of measures / packages / variants assessed, a specific cost curve (= lower border of the area marked by the data points of the different variants) can be developed (EC, 2012b).

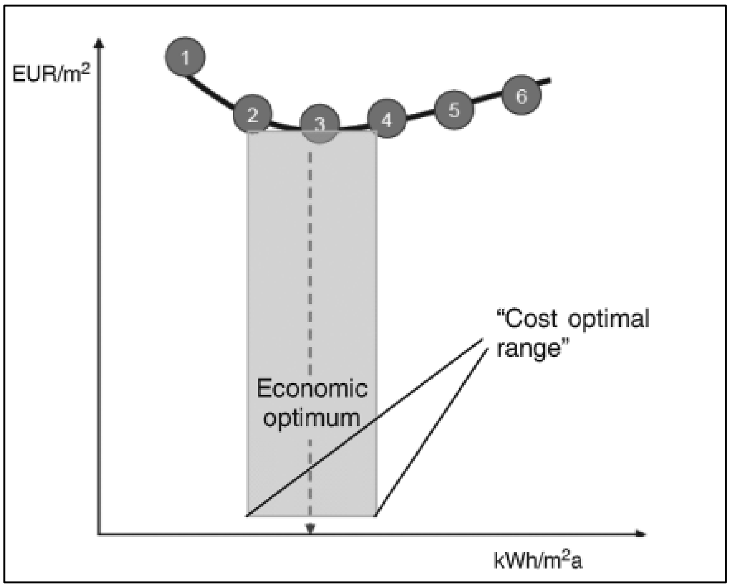

Figure 19. Different variants within the graph and position of the cost-optimal range (Boermans et al., 2011; EC, 2012b)

The combination of packages with the lowest cost is the lowest point of the curve (in the illustration above, package '3'). Its position on the x-axis automatically gives the cost-optimal level of minimum energy performance requirements. As stipulated in paragraph 2 of Annex I(6) to the Regulation 244/2012, if packages have the same or very similar costs, the package with the lower primary energy use (= left border of the cost-optimal range) should if possible guide the definition of the cost-optimum level (EC, 2012b).

Ecofys has developed a cost-optimality tool according to the requirements as defined in Commission Delegated Regulation (244/2012). The model calculates cost-optimal building configurations (considering both, demand and supply side) for different reference buildings under varying climatic conditions. The model can be adopted to local conditions. With regard to physical issues, local construction practices as well as climatic circumstances are taken into consideration for instance, in order to calculate hourly heating and cooling demands as specified by EU norm DIN EN ISO 13790. These calculated heating and cooling demands feed into the calculation of global costs, along with micro- and macroeconomic parameters such as dynamic costs for building components and variable energy prices. The model calculates thousands of combinations of U-values, heating and cooling systems and identifies the technical configuration which yields the lowest global costs over the calculation period. A private or societal perspective can be adopted for defining cost-optimality. As well, the calculation model can be applied to both new and renovated buildings and is able to include typical local reference buildings and geometries.

The analyses will be conducted on reference building level and results extrapolated to the entire building stock. A reference building is a building that represents a typical building of the building stock. This allows analysing an entire building stock by conducting analyses from bottom-up, on different reference buildings. Typical residential reference buildings are e.g. detached or semi-detached single and multi-family houses of different sizes and/or age classes (construction phases). Which reference building should be used, significantly depends on the shares in the building stock. In countries which are dominated by single-family houses, focus should be on this kind of buildings. For the analyses it was necessary to investigate the typical construction characteristics of the considered building type, e.g. size, geometries, used construction materials, typical HVAC equipment (space heating and cooling systems etc.), kind and size of windows, orientation etc. Based on the 2011 and 2001 census results, it has been decided to use a 5 story multi-family house as this kind of buildings is most present in the building stock and therefore most relevant for this analysis. All details incl. drawings of the used reference building can be found in ANNEX 4 of this report.

The calculation parameters can be found in ANNEX 2 (new constructions) and ANNEX 3 (renovations), the investment cost assumptions in ANNEX 5.

3.2 Results

The following tables present the final results of the cost-optimality calculations and also current requirements according to TS825 in order to highlight the higher ambition. For the calculation of the primary energy demand for space heating and space cooling, primary energy factors of 1.0 for gas and 2.36 for electricity have been used (Ganiç and Yılmaz, 2014; Mangan and Oral, 2016a). It should be considered that the same calculation parameters have been used for both the energy demand calculations according to TS825 and cost-optimality (see ANNEX 2 & 3). Considering that these parameters and the whole methodology based on EN 13790 can differ from TS825, also the calculated energy demand benchmarks can differ to those provided in TS825. U-values are presented in W/(m²*K), specific primary energy demand in kWh/(m²*a), heating and cooling load in kW.

Table 3. Results of the cost-optimality calculations for new constructions

Cost-optimal U-values and resulting primary energy demand for new constructions												
City	**Antalya**	**İzmir**	**Gaziantep**	**Muğla**	**İstanbul**	**Bursa**	**Ankara**	**Niğde**	**Sivas**	**Ağrı**	**Kars**	**Erzurum**
U-value roof	0.27	0.22	0.21	0.19	0.19	0.20	0.16	0.16	0.16	0.15	0.13	0.13
U-value façade	0.35	0.29	0.27	0.27	0.28	0.27	0.21	0.21	0.22	0.20	0.18	0.17
U-value windows	1.80	1.80	1.80	1.80	1.80	1.10	1.10	1.10	1.10	1.10	1.10	1.10
U-value ground	0.57	0.45	0.41	0.43	0.43	0.41	0.30	0.35	0.36	0.32	0.29	0.26
Primary energy (heating & cooling)	34.9	48.4	59.9	56.0	45.6	48.8	65.6	63.7	75.1	91.0	103.2	106.4
Primary energy (space heating)	15.6	32.4	41.0	42.9	37.1	39.5	58.8	56.9	70.9	88.3	102.4	105.0
Primary energy (space cooling)	19.3	16.1	18.9	13.0	8.6	9.3	6.8	6.8	4.1	2.7	0.8	1.4
Heating load	22.2	31.2	34.4	32.4	30.6	32.0	42.0	42.4	48.0	56.1	60.2	62.5
Cooling load	29.2	26.9	30.2	26.2	17.6	20.9	19.0	17.5	17.3	12.1	8.0	11.2

Table 4. Results of the cost-optimality calculations for renovations

Cost-optimal U-values and resulting primary energy demand for renovations												
City	**Antalya**	**İzmir**	**Gaziantep**	**Muğla**	**İstanbul**	**Bursa**	**Ankara**	**Niğde**	**Sivas**	**Ağrı**	**Kars**	**Erzurum**
U-value roof	0.25	0.20	0.20	0.19	0.20	0.22	0.15	0.15	0.17	0.15	0.13	0.12
U-value façade	0.35	0.29	0.28	0.27	0.28	0.27	0.22	0.22	0.22	0.21	0.18	0.17
U-value windows	1.80	1.80	1.10	1.10	1.30	1.10	1.10	1.10	1.10	1.10	1.10	1.10
U-value ground	0.51	0.41	0.43	0.41	0.41	0.41	0.33	0.34	0.33	0.31	0.27	0.25
Primary energy	42.5	56.6	66.4	60.7	50.0	56.3	74.9	72.5	84.8	102.5	115.2	119.0
Primary energy (space heating)	17.4	35.8	42.2	44.0	39.0	44.4	66.3	64.0	79.6	99.3	114.2	117.3
Primary energy (space cooling)	25.0	20.7	24.2	16.7	11.0	11.9	8.6	8.6	5.2	3.3	0.9	1.7
Heating load	23.1	32.4	33.8	31.5	30.5	33.8	44.3	44.5	50.8	59.2	63.1	65.6
Cooling load	29.9	27.5	29.9	25.8	17.6	21.4	19.5	17.9	17.7	12.3	8.0	11.3

Table 5. Current U-value requirements according to TS825 and calculated primary energy demands according to EN 13790

Current U-value requirements according to TS825 and calculated primary energy demands according to EN 13790												
City	**Antalya**	**İzmir**	**Gaziantep**	**Muğla**	**İstanbul**	**Bursa**	**Ankara**	**Niğde**	**Sivas**	**Ağrı**	**Kars**	**Erzurum**
U-value roof	0.45	0.45	0.40	0.40	0.40	0.40	0.30	0.30	0.25	0.25	0.25	0.25
U-value façade	0.70	0.70	0.60	0.60	0.60	0.60	0.50	0.50	0.40	0.40	0.40	0.40
U-value windows	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
U-value ground	0.70	0.70	0.60	0.60	0.60	0.60	0.45	0.45	0.40	0.40	0.40	0.40
Primary energy new	43.4	64.3	76.8	72.0	59.2	68.2	91.0	89.5	97.9	120.5	140.6	145.6
Primary energy new (space heating)	23.0	47.5	56.9	58.5	50.8	59.0	84.7	83.5	94.3	118.5	140.2	144.6
Primary energy new (space cooling)	20.4	16.8	20.0	13.4	8.4	9.2	6.3	6.0	3.6	2.0	0.4	1.0
Heating load new	29.4	43.3	44.7	43.1	39.8	45.7	56.9	57.8	62.5	72.4	78.8	83.4
Cooling load new	34.5	32.5	35.6	30.6	19.8	25.3	22.4	20.2	19.5	13.1	8.1	12.2
Primary energy ren.	49.7	72.0	86.3	80.2	65.7	75.7	100.5	99.1	108.2	132.8	154.9	160.3
Primary energy ren. (space heating)	25.5	52.2	62.6	64.3	55.9	64.8	93.2	92.2	104.0	130.5	154.4	159.2
Primary energy ren. (space cooling)	24.2	19.8	23.7	15.9	9.9	10.8	7.3	6.9	4.2	2.3	0.5	1.1

As can be seen in the tables above, cost-optimal u-values for renovations in some cases are slightly better than for new constructions. Main reasons for this result are the assumed efficiencies of the space heating and space cooling supply systems which are significantly worse in the renovation case. These low efficiencies lead to more energy cost savings when improving the building envelope. As investment costs for renovations are assumed to be just a bit higher for façade renovations, this leads to more ambitious cost-optimal values over the calculation period of 30 years.

The following Table 6 and Table 7 present the results of the cost-optimality calculations adjusted to the six climate regions as used in this report (see chapter 2.3). The results represent the average of the covered reference cities in the respective regions.

Table 6. Results of the cost-optimality calculations for new buildings adjusted to the six climate regions as used in this report

Component	Unit	Hot	Cooling-based	Moderate	Rather cold	Medium cold	Cold
Roof	W/(m²*K)	0.27	0.21	0.19	0.16	0.16	0.14
Façade	W/(m²*K)	0.35	0.28	0.27	0.21	0.22	0.18
Windows	W/(m²*K)	1.80	1.80	1.57	1.10	1.10	1.10
Ground	W/(m²*K)	0.57	0.43	0.42	0.32	0.36	0.29
Primary energy demand (cost-optimality)	kWh/(m²*a)	34.9	54.2	50.1	64.7	75.1	100.2
Primary energy demand (U-values TS825)	kWh/(m²*a)	43.4	70.6	66.5	90.2	97.9	135.6

Table 7. Results of the cost-optimality calculations for existing buildings to be renovated adjusted to the six climate regions as used in this report

Component	Unit	Hot	Cooling-based	Moderate	Rather cold	Medium cold	Cold
Roof	W/(m²*K)	0.25	0.20	0.20	0.15	0.17	0.13
Façade	W/(m²*K)	0.35	0.28	0.27	0.22	0.22	0.19
Windows	W/(m²*K)	1.80	1.45	1.17	1.10	1.10	1.10
Ground	W/(m²*K)	0.51	0.42	0.41	0.34	0.33	0.28
Primary energy demand (cost-optimality)	kWh/(m²*a)	42.5	61.5	55.7	73.7	84.8	112.2
Primary energy demand (U-values TS825)	kWh/(m²*a)	49.7	79.2	73.9	99.8	108.2	149.4

The following eight subchapters contain for both construction types (new buildings and renovations) and for each of the covered building elements (wall, roof, windows and floors) a vector and a raster based map. The vector based maps visualise the results as presented in Table 6 and Table 7 on a vector base meaning for each province depending to which of the six climate regions they are assigned to.

In contrast, the raster based maps do not use information for each province but based on 51 defined locations (points/cities) on the map and assumed similarities with the analysed 12 reference cities, ArcGIS interpolates information and creates "flowing colour schemes". These maps are less stringent but more intuitive as climate usually does not just change at a province (administrative) border.

3.2.1 Cost-optimal U-values for walls in new constructions

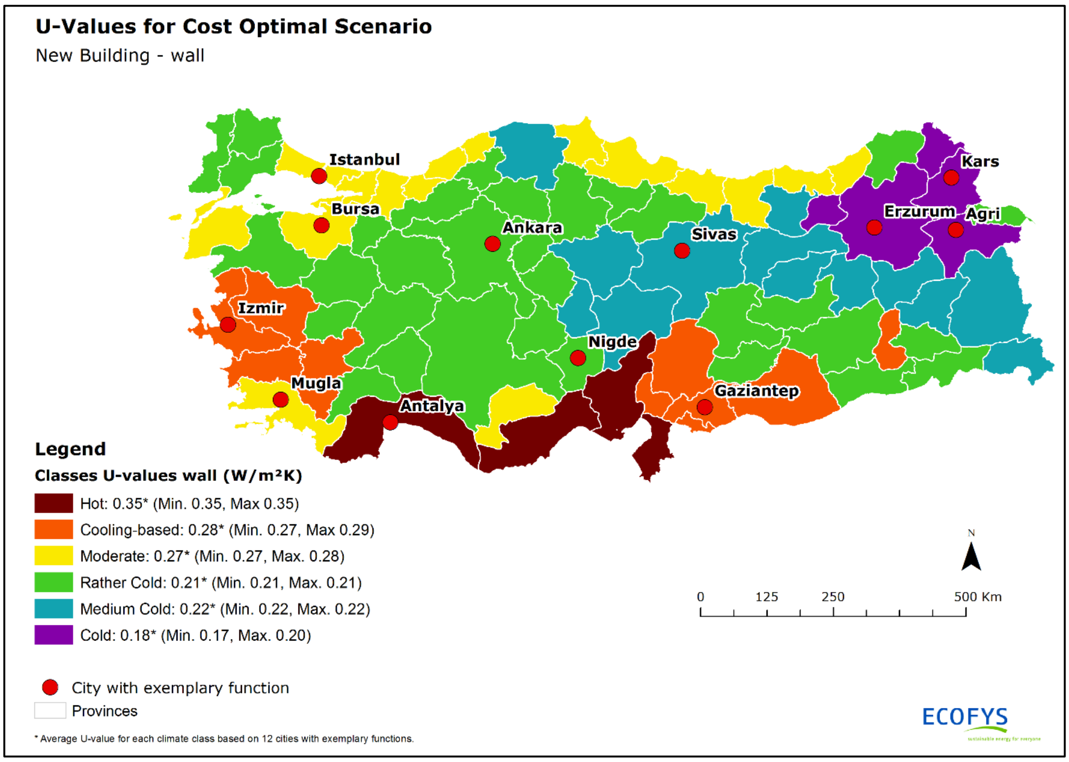

Figure 20 - Vector based map on cost-optimal U-values for walls in Turkish new constructions 2015

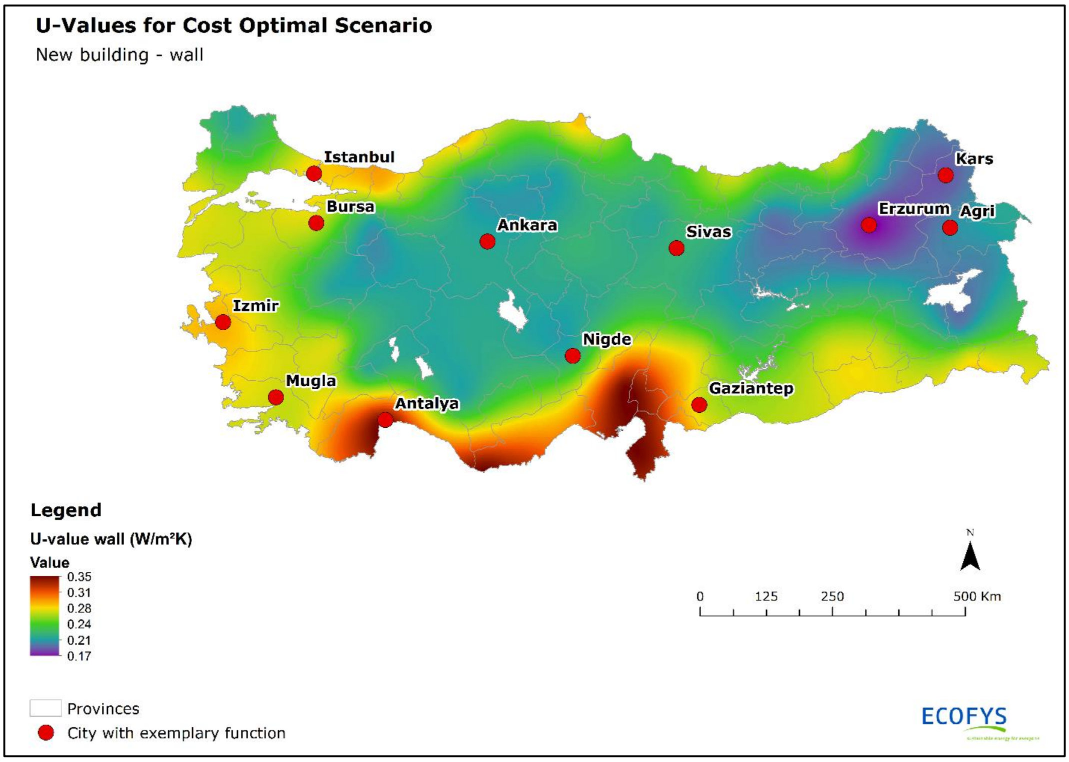

Figure 21 - Raster based map on cost-optimal U-values for walls in Turkish new constructions 2015

3.2.2 Cost-optimal U-values for roofs in new constructions

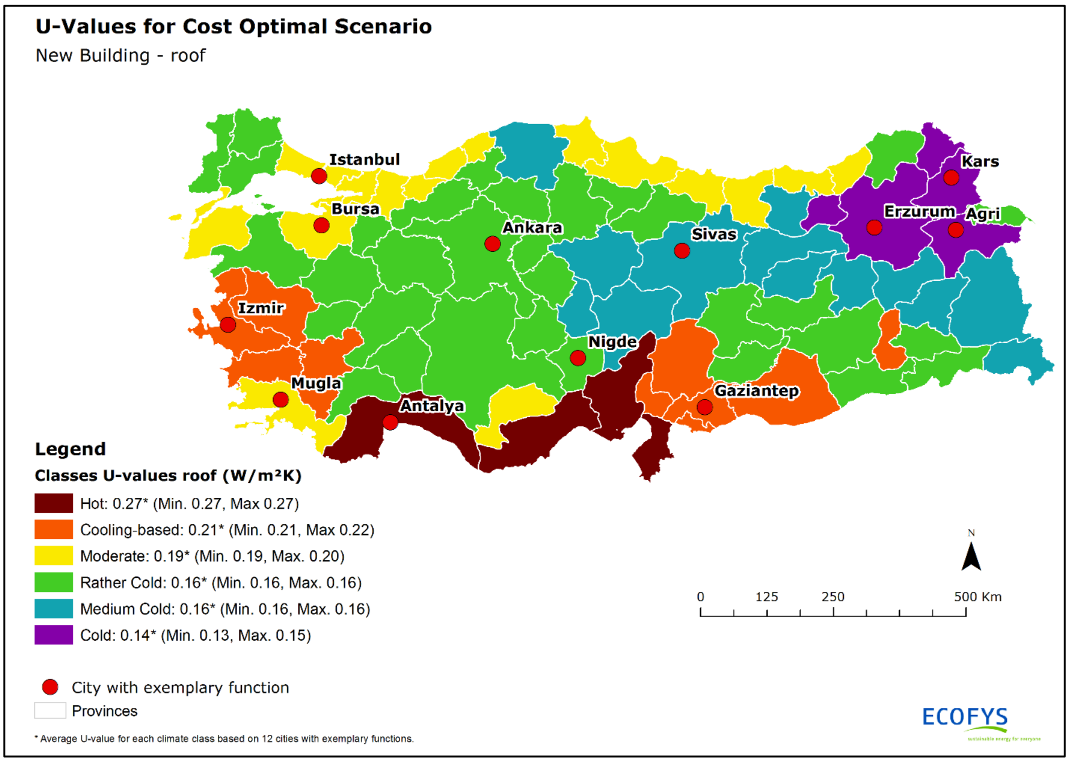

Figure 22 - Vector based map on cost-optimal U-values for roofs in Turkish new constructions 2015

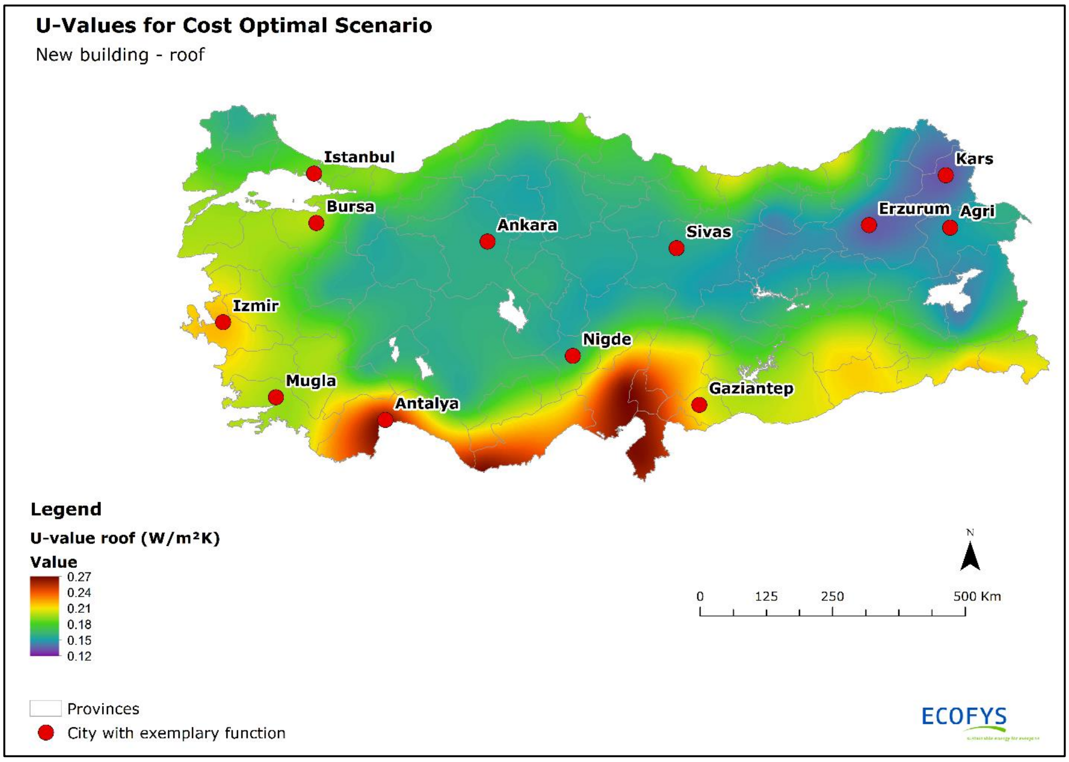

Figure 23 - Raster based map on cost-optimal U-values for roofs in Turkish new constructions 2015

3.2.3 Cost-optimal U-values for ground floors in new constructions

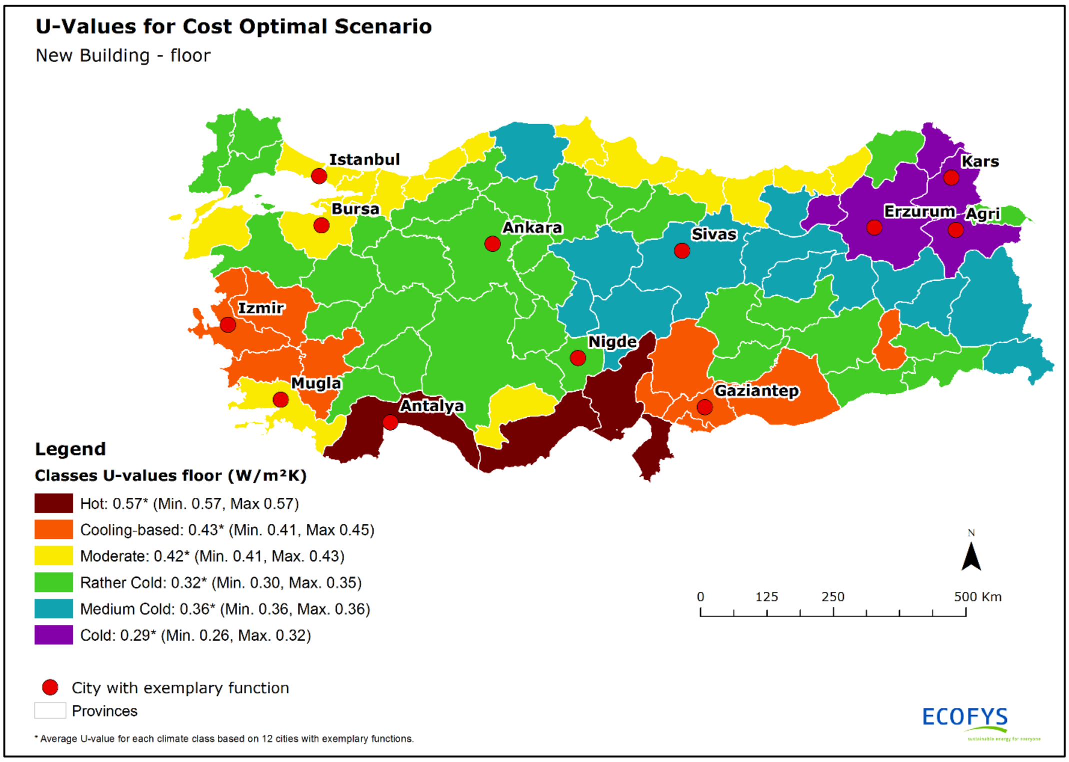

Figure 24 - Vector based map on cost-optimal U-values for ground floors in Turkish new constructions 2015

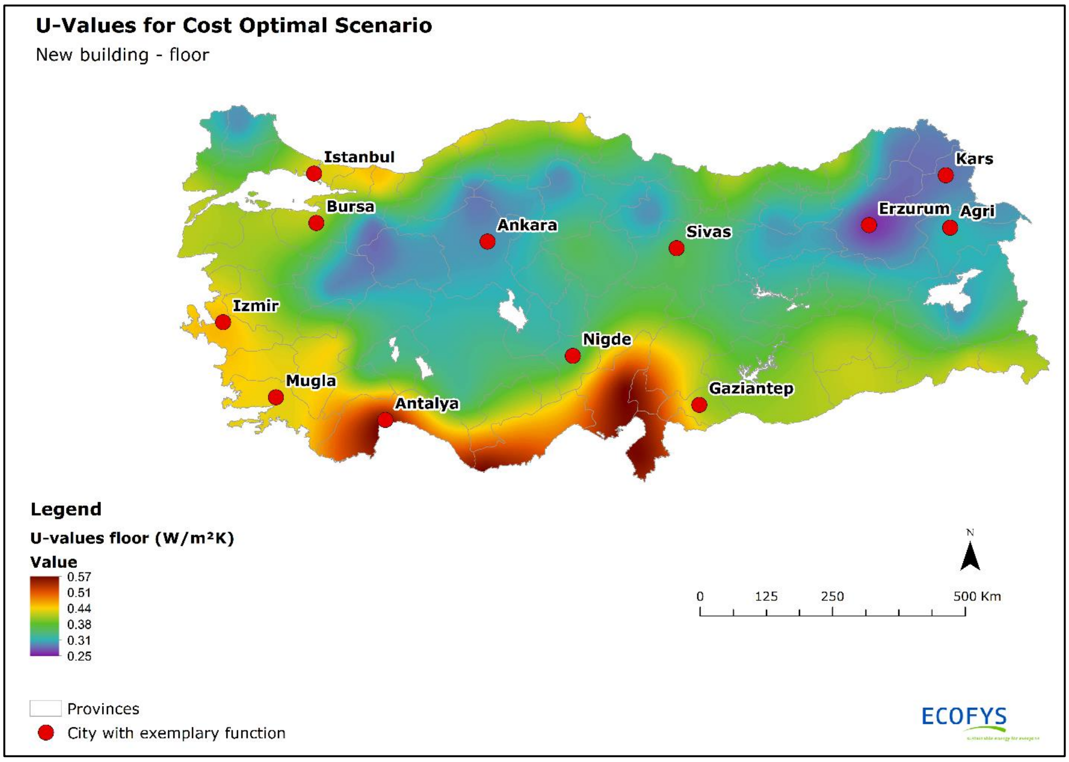

Figure 25 - Raster based map on cost-optimal U-values for ground floors in Turkish new constructions 2015

3.2.4 Cost-optimal U-values for windows in new constructions

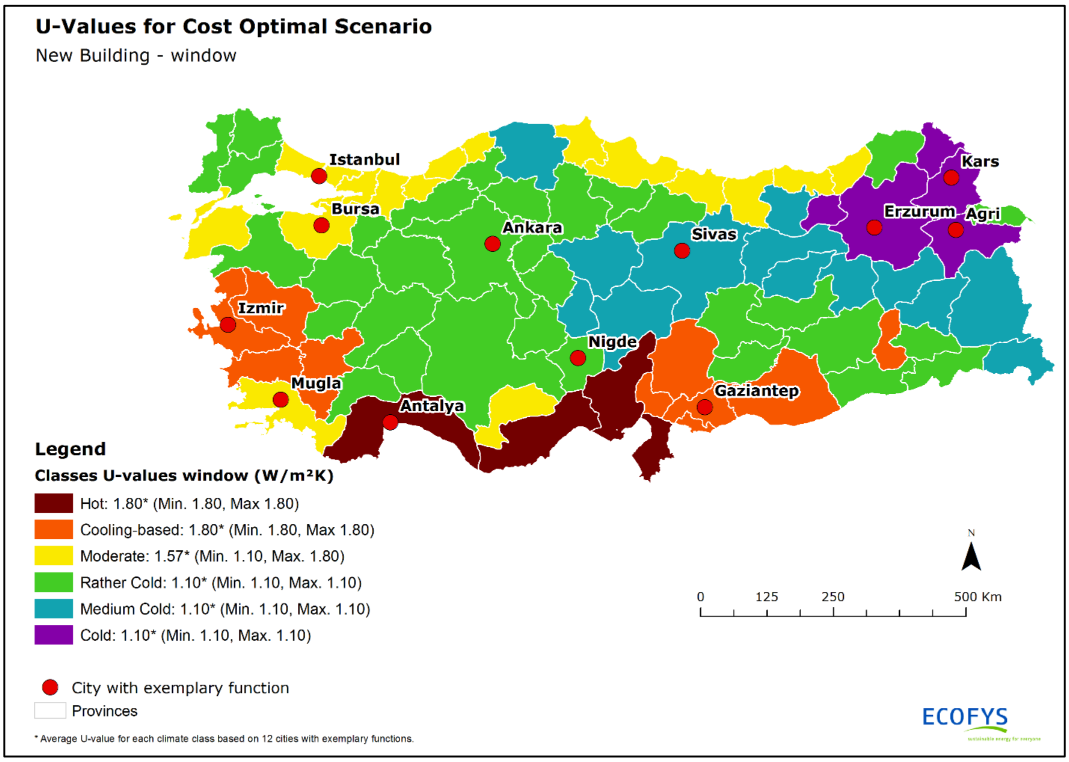

Figure 26 - Vector based map on cost-optimal U-values for windows in Turkish new constructions 2015

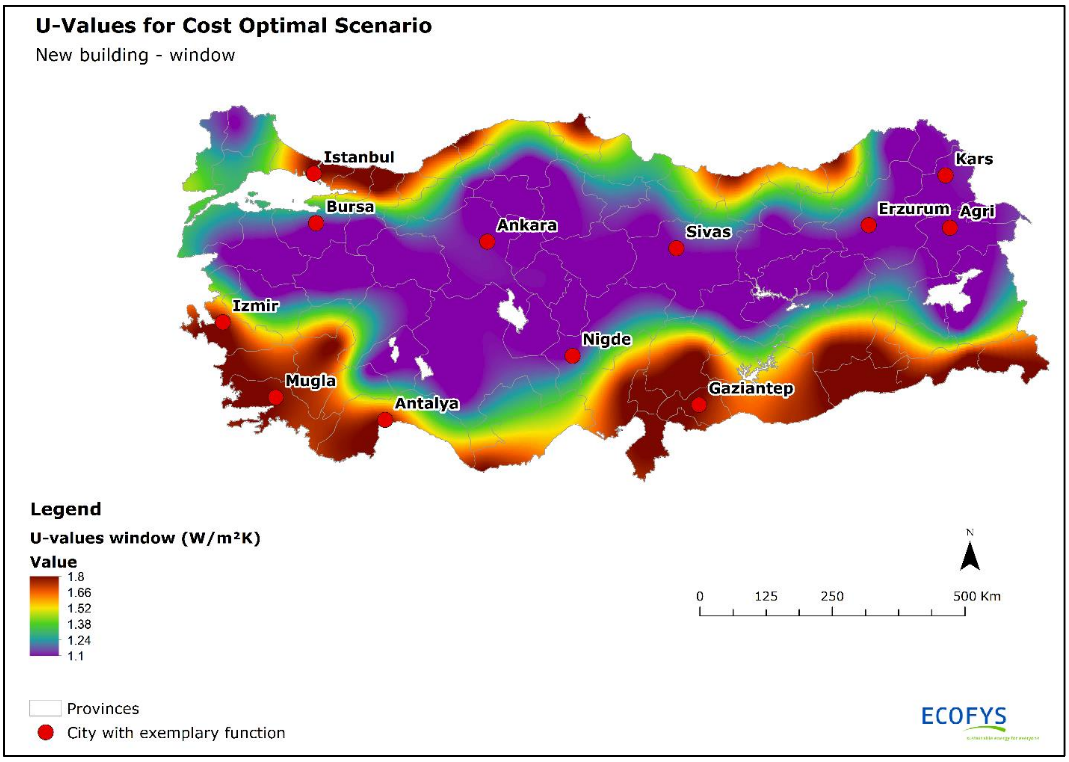

Figure 27 - Raster based map on cost-optimal U-values for windows in Turkish new constructions 2015

3.2.5 Cost-optimal U-values for walls in existing buildings to be renovated

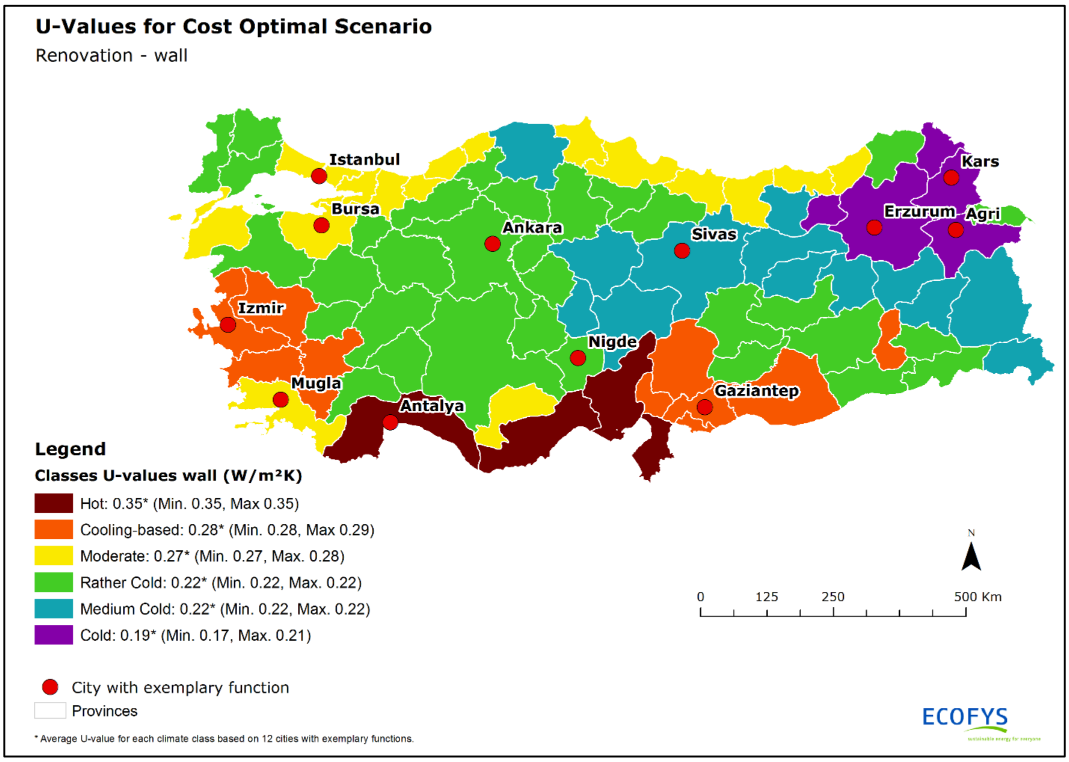

Figure 28 - Vector based map on cost-optimal U-values for walls in Turkish existing buildings to be renovated 2015

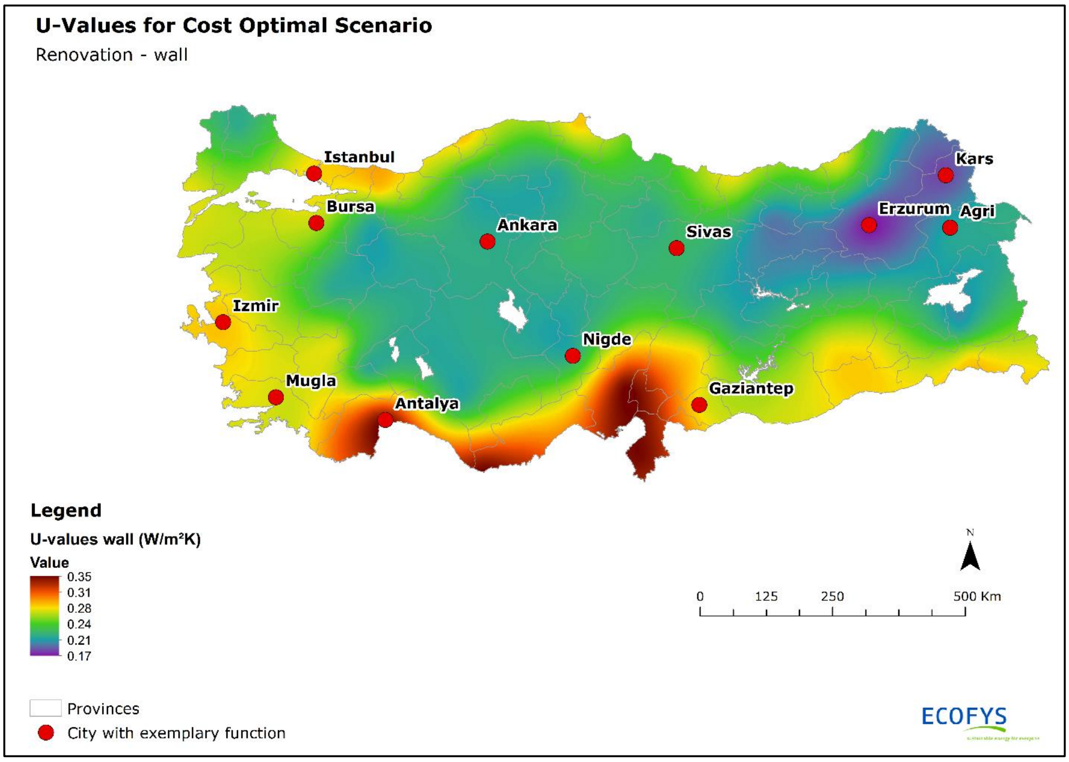

Figure 29 - Raster based map on cost-optimal U-values for walls in Turkish existing buildings to be renovated 2015

3.2.6 Cost-optimal U-values for roofs in existing buildings to be renovated

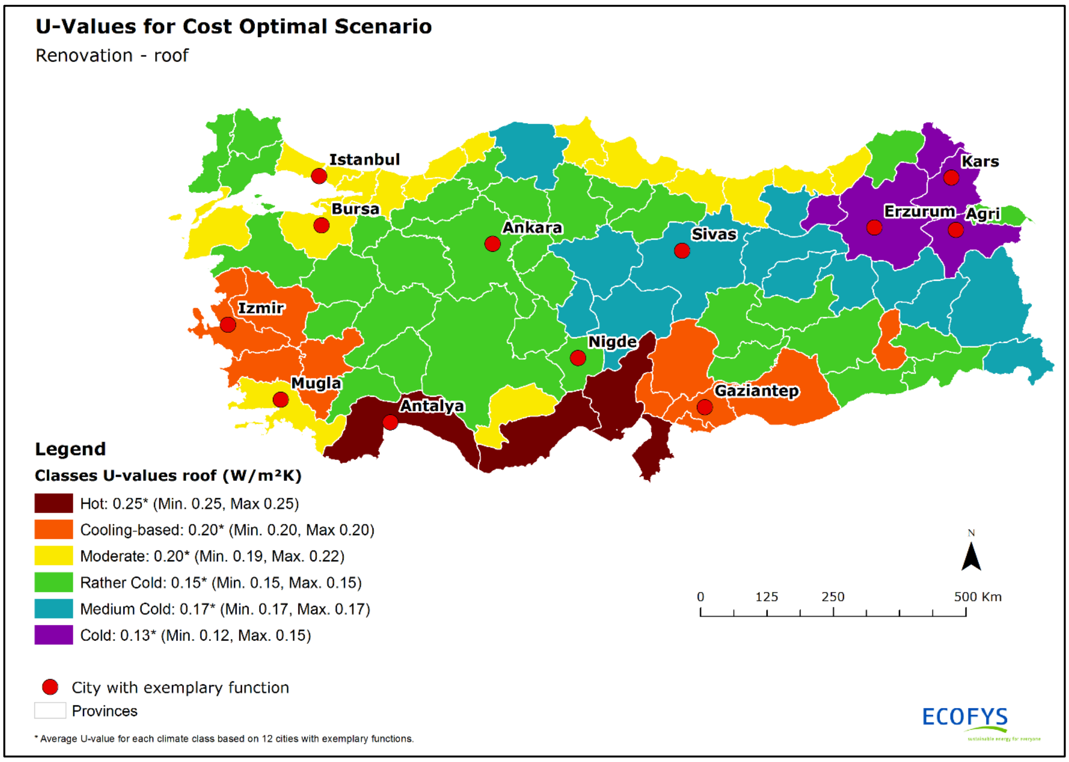

Figure 30 - Vector based map on cost-optimal U-values for roofs in Turkish existing buildings to be renovated 2015

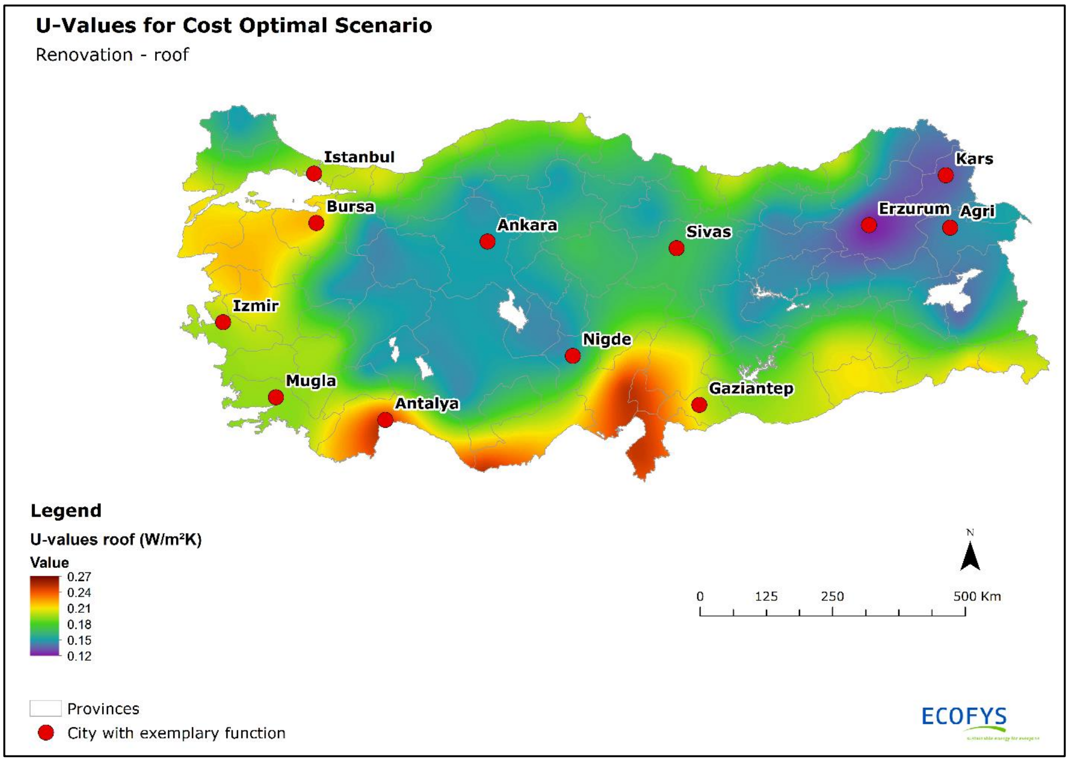

Figure 31 - Raster based map on cost-optimal U-values for roofs in Turkish existing buildings to be renovated 2015

3.2.7 Cost-optimal U-values for ground floors in existing buildings to be renovated

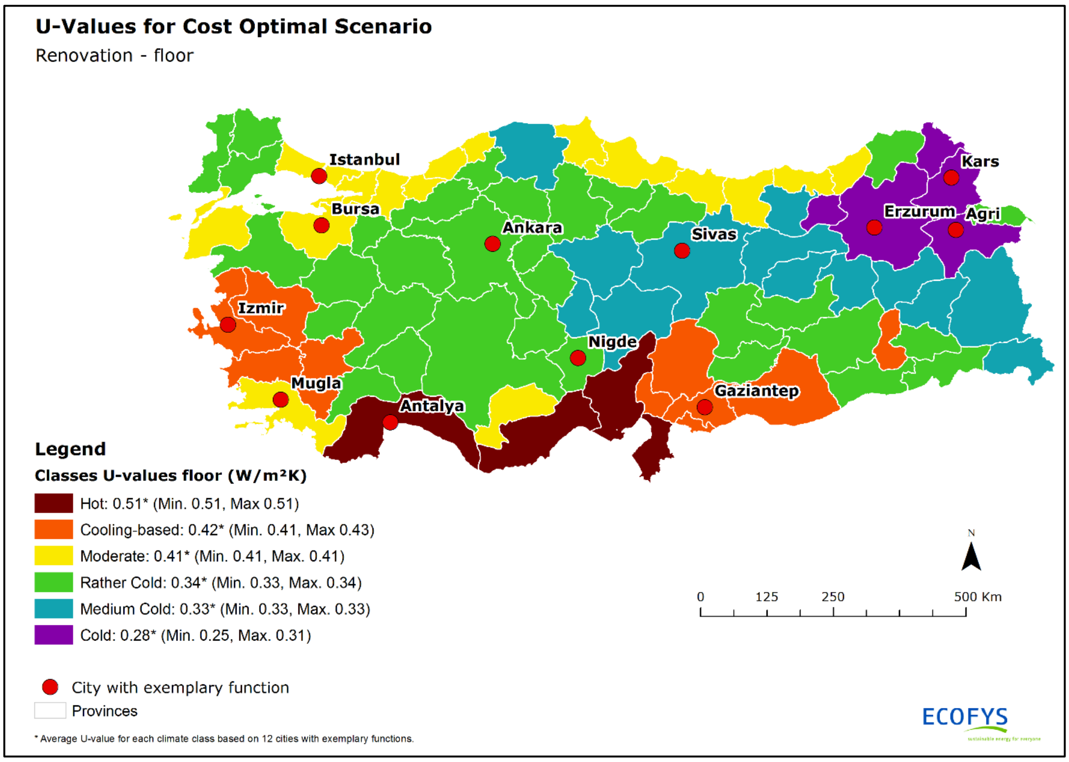

Figure 32 - Vector based map on cost-optimal U-values for ground floors in Turkish existing buildings 2015

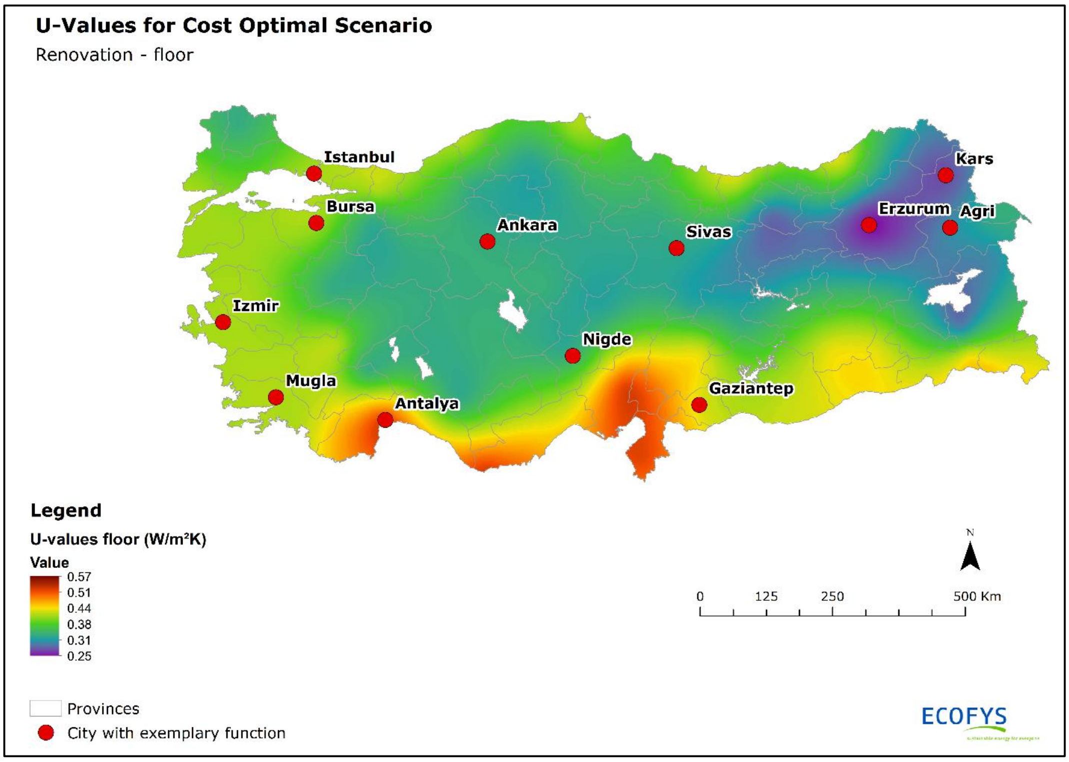

Figure 33 - Raster based map on cost-optimal U-values for ground floors in Turkish existing buildings 2015

3.2.8 Cost-optimal U-values for windows in existing buildings to be renovated

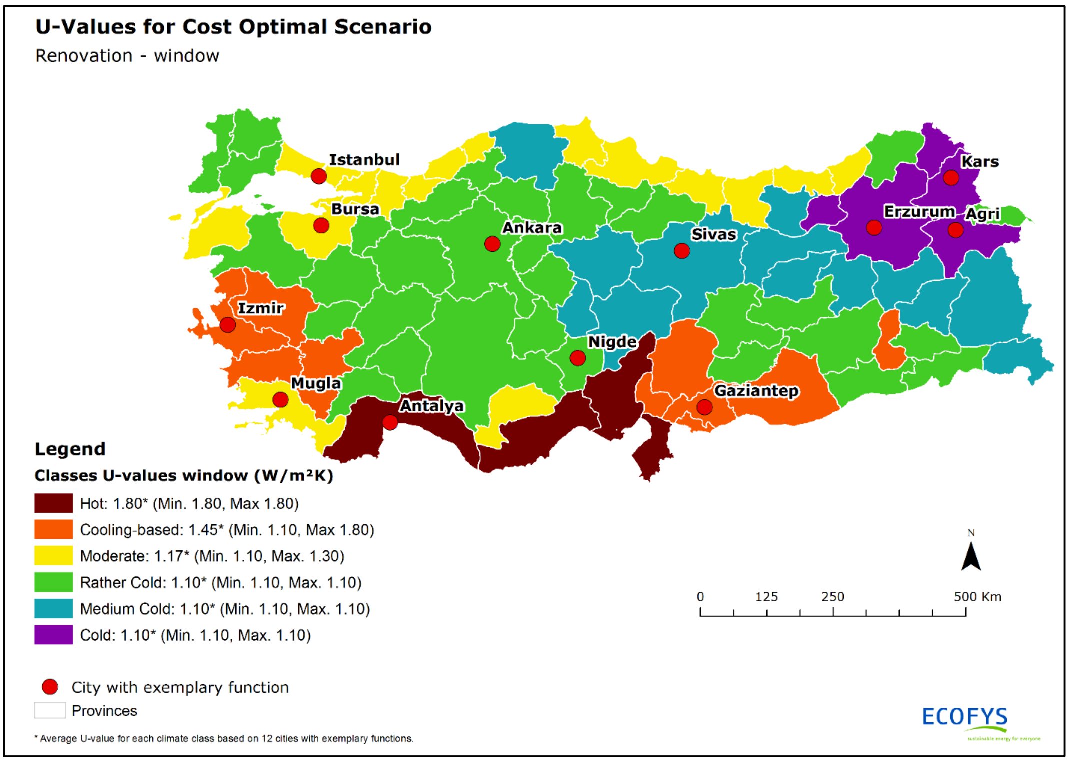

Figure 34 - Vector based map on cost-optimal U-values for windows in Turkish existing buildings to be renovated

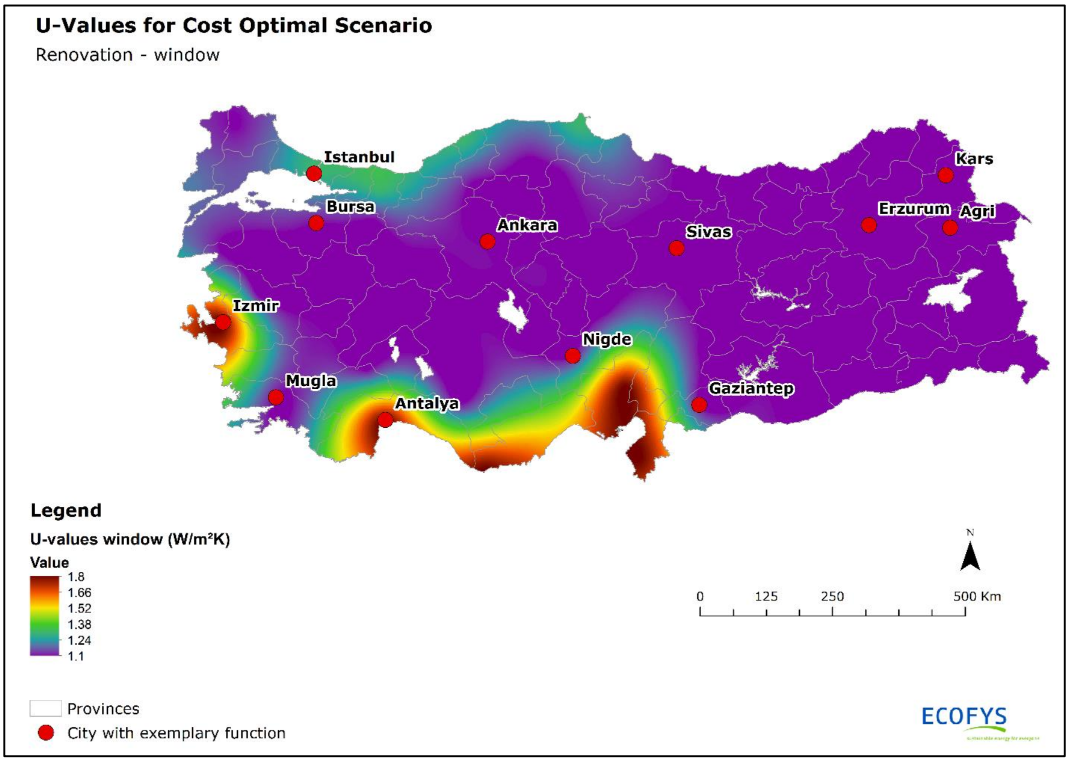

Figure 35 - Raster based map on cost-optimal U-values for windows in Turkish existing buildings to be renovated

4 Energy saving potential by application of cost-optimal U-values

This chapter assesses the future energy saving potential from cost-optimal U-values compared to the BAU scenario. For this purpose it is necessary to know the current building stock size, energy consumption by energy use and energy carrier and to use realistic assumptions for the future development. The methodology is described in the following chapter 4.1, the results in chapter 4.2.

4.1 Methodology

4.1.1 Current building stock size

For estimating the current building stock size, no official statistic is available but a number of other useful sources are available and have been used:

- Census 2011 data
- Census 2001 data
- Building permits since 1954

With these main sources of information, it is possible to get a well based picture of the current residential building stock in Turkey as a whole but also per province. Bringing all sources together, we estimate that the current residential building stock comprises approximately 2,375 million square metre floor area. This leads to an average floor space per capita of approximately 30 m² which correlates with benchmarks from other comparable countries worldwide.

According to the methodology as described in chapter 2.2 and the 6 defined climate regions as used in this report, the building stock is allocated to these regions as presented in the following table:

Table 8. Residential building stock in Turkey 2015 separated by climate region

Climate region		Residential floor area in stock [Mio m²]
1	Hot	230.5
2	Cooling-based	397.6
3	Moderate	842.9
4	Rather cold	706.2
5	Medium cold	155.7
6	Cold	41.8
Turkey		**2,374.6**

4.1.2 Future building stock development

For the expected future development of the building stock, a methodology developed by Ecofys is used and which has already been used in several other studies (such as Ecofys & IEEJ (2015) and Molenbroek et al. (2015)). The approach uses correlations between economic strength (measured in GDP/capita) and available floor space (see following figure).

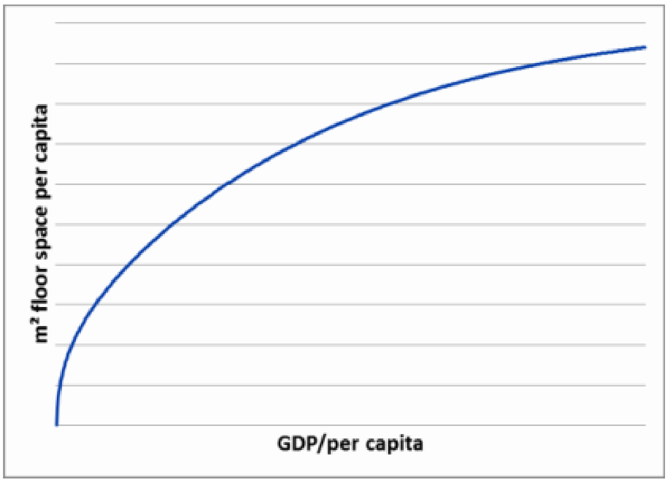

Figure 36. Qualitative illustration of correlation between GDP per capita and available floor space per capita

Population growth data has been extracted from the UN World Population Prospects: The 2015 Revision "Medium Variant", GDP growth assumptions from OECD Economic Outlook "Long-term growth scenarios" (real GDP growth is expected with 5.2% between 2012-2017, 4.1% between 2018-2030 and 2.3% between 2031-2050).

Our methodology allows the calculation of residential and non-residential floor space separately and is based on Ecofys` experiences in building stock research (most of them are confidential market research projects. However published examples comprise Ecofys & IEEJ (2015) "renovation tracks Europe" (Boermans et al., 2012), heat pump implementation scenarios (Bettgenhäuser et al., 2013) or the Panorama of the European non-residential construction sector (Schimschar et al., 2011). The model and its underlying formulas are based on building stock statistics from about 50 countries worldwide and has continuously improved over recent years (ongoing confidential PhD thesis work (Schimschar, 2015). The model is based on Isaac & van Vuuren (2009) and uses average correlations between GDP per capita and residential living space (in this sense "average" means the average between different kinds of building categories such as detached and attached single and multi-family houses from different world regions). Also typical correlations between the residential and non-residential floor space can be used.

We have developed 2 scenarios, a Business as Usual (BAU) scenario and a cost-optimality (cost-opt) scenario. In addition to the new construction rate, which is a result of the above described approach and that is changing over time, for both scenarios, the following demolition and renovations rates have been used:

Table 9. Used metabolism rates for the two scenarios

Metabolism rate	Rate in percent of the stock per year	Source
Demolition rate	1.5%	Based on Elsland et al., 2014
Energy related renovation rate containing the thermal improvement of the building envelope[3]	0.45%	Based on Elsland et al., 2014

Especially the 1.5% demolition rate is comparably special. Reason for this high demolition activity is Turkey's Urban Transformation Plan that requires 6.5 million dwellings to be demolished by 2030 (Elsland et al., 2014).

4.1.3 Energy consumption

Information on the total energy consumption in Turkey's residential building sector also divided by energy carrier has been extracted from EUROSTAT's complete energy balances - annual data (EUROSAT, 2016). According to several sources (Utlu & Hepbasli (2003), Nishimura et al. (2011), Elsland et al., 2014, UNDP & GEF (2011)), the total energy consumption has been allocated to different energy uses and results compared with benchmarks from other countries. As a result it was possible to calculate and define the current space heating and space cooling consumption which were estimated to be 79.5 TWh for space heating and 2.1 TWh for space cooling in 2015.

For the prediction of the future energy consumption development it needs to be considered that the current consumption does not equal the calculated energy demand (which is normal). Many low income households are living in cold parts of the country, having limited financial means for heating up their houses. In those cases, often not all parts of the building are heated in the same way and people do not heat their building during the entire heating period to e.g. 20°C. Often, e.g. sleeping rooms, kitchens, bathrooms etc. are not heated or cooled. Therefore a significant discrepancy between theoretical demand and actual consumption can occur.

We have calculated a final space heating energy demand of ~227 TWh in 2015 and a final space cooling demand of ~14 TWh leading to the finding that just about 35% of the theoretical space heating demand is currently covered and 14% of the space cooling demand. For our scenarios we have assumed that these shares will rise linearly to 70% (heating) respectively 50% (cooling) by 2050.

[3] Elsland et al. (2014) assume a current energetic and non-energetic refurbishment rate of 0.9% per year. 50% of these renovations also leads to a thermal improvement of the building envelope (=0.45%)

4.2 Results

The following figure presents the expected residential building stock development between 2015 and 2050 assuming the metabolism rates as defined in Table 9 and the new construction rates that result from the expected stock growth according to the methodology as described in chapter 4.1.

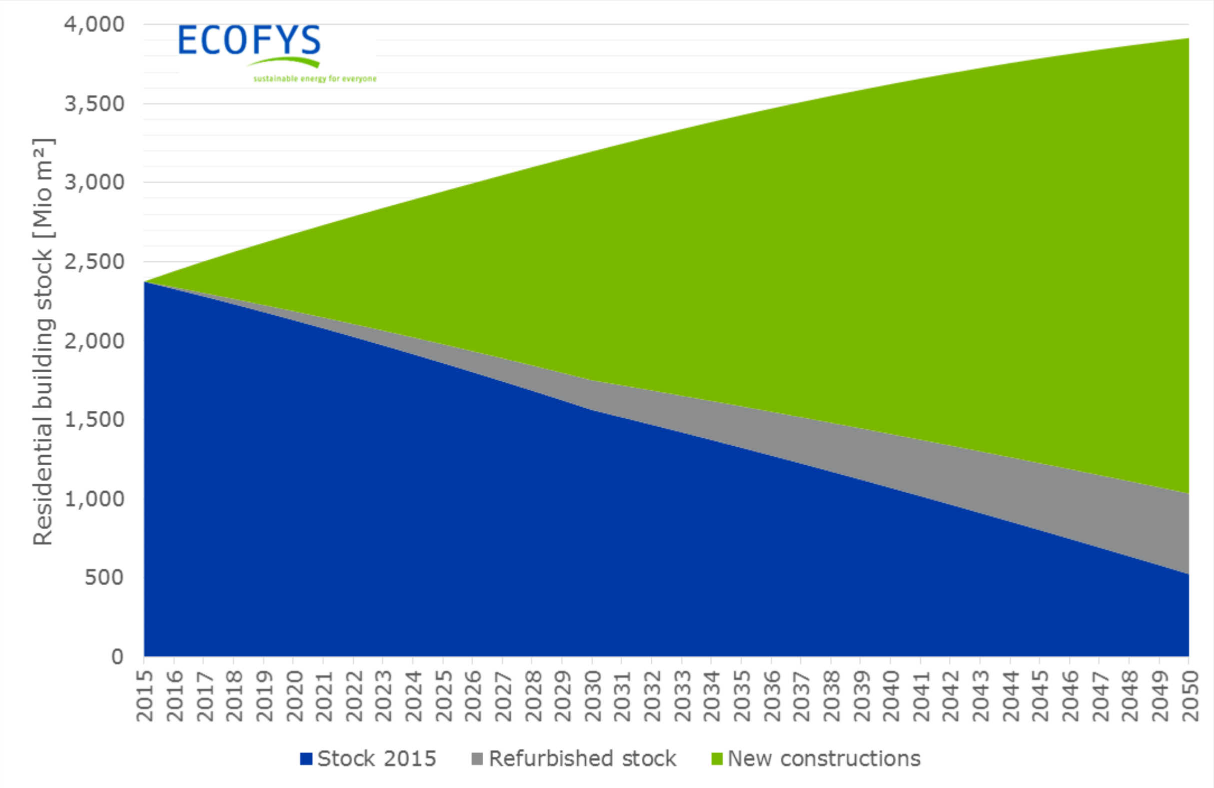

Figure 37. Residential building stock development in Turkey 2015-2050

Figure 37shows that it is expected that the residential building stock will grow from ~2,375 million square metre in 2015 to almost 4,000 million square metre in 2050. This is an increase of ~65%.

Based on the number of newly constructed buildings according to TS825, demolished buildings in the stock (typical uninsulated buildings in the stock) and BAU renovations, Figure 38 presents the expected Business-as-Usual final energy consumption development for space heating and space cooling 2015-2050. The also illustrated cost-optimality path assumes that all new constructions and renovations are realised according to calculated cost-optimal levels as presented in chapter 3.2.

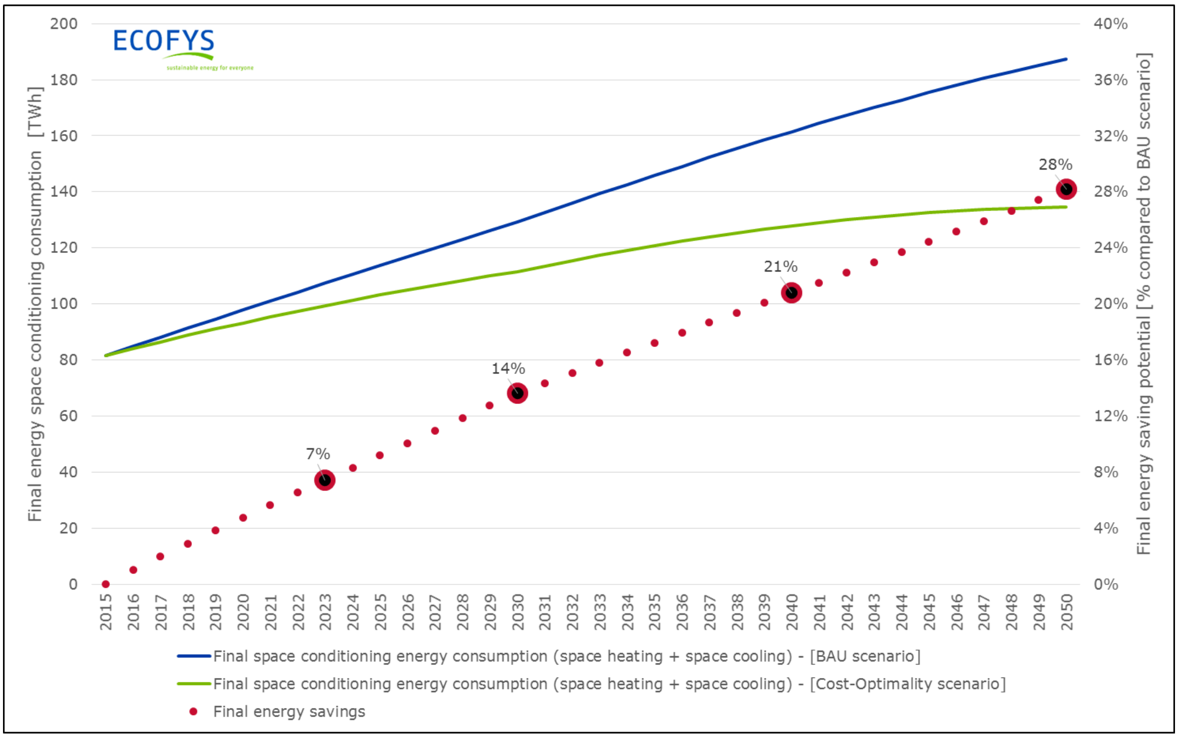

Figure 38. Projected final energy consumption for space conditioning (space heating and space cooling) in Turkey's residential building sector 2015-2050 in the BAU and the cost-opt scenarios and the resulting final energy savings in the cost-opt scenario compared to the BAU scenario

Apart from the two scenarios, Figure 38 illustrates the final energy saving potential between the two scenarios. We have calculated a reduction of ~7% in 2023, 14% in 2030, 21% in 2040 and 28% in 2050.

5 U-Values according to climate protection targets

On September 30th 2015, the Republic of Turkey has officially submitted its "Intended Nationally Determined Contribution" (INDC) to the UNFCCC. In this INDC it defines the climate protection target of reducing its greenhouse gas emissions by up to 21% from the Business as Usual (BAU) level by 2030. Related to "Buildings and Urban Transformation" the INDC states the following plans and policies to be implemented:

- Constructing new residential buildings and service buildings as energy efficient in accordance with the Energy Performance of Buildings Regulations
- Creating Energy Performance Certificates for new and existing buildings so as to control energy consumption and greenhouse gas emissions and to reduce energy consumption per square meter
- Reducing the consumption of primary energy sources of new and existing buildings by means of design, technological equipment, building materials, development of channels that promote the use of renewable energy sources (loans, tax reduction, etc.)
- Dissemination of Green Building, passive energy, zero-energy house design in order to minimize the energy demand and to ensure local production of energy

Especially related to the first plan, there is a clear connection to the EPBD. Energy Efficiency requirements for new buildings according to the EPBD are cost-optimality requirements for all new buildings. Therefore, the following paragraphs show how the calculated cost-optimality standards support the climate protection target as defined in the INDC and also indicate the remaining gap.

According to chapter 4, by implementing the calculated cost-optimality standards, an energy saving reduction of approximately 14% can be achieved. Using IPCC standard emission factors for fossil fuels and an emission factor of 0.55 kg CO_{2e}/kWh for electricity and assuming that the emission factors keep stable until 2030, this energy saving potential correlates with an emission reduction potential of ~12% until 2030. The applied emission factors are listed in the following table.

Table 10. Assumed emission factors and shares in the space heating fuel mix

Energy carrier	Emission factor [kg CO_{2e} / kWh]	Shares in space heating fuel mix[4]	Sources
Coal	0.34	13%	Emission factors: • IPCC (2006) Shares in heating fuel mix: • http://www.eigm.gov.tr/tr-TR/Sayfalar/Sankey-Diyagramlari
Petroleum (mainly LPG)	0.23	6%	
Natural gas	0.20	46%	
Renewable energies including solid, liquid and gaseous bioenergy (incl. traditional biomass usually used in rural areas as fire wood), solar, geothermal and wind (if applicable on buildings).	0.00[5]	35%	
Weighted space heating fuel mix	0.151	100%	
Electricity	0.55	Only space cooling	Mangan & Oral 2016a, Mangan & Oral 2016b

In order to close the remaining gap of ~9% to reach the targeted 21% reduction with a focus on energy efficiency measures on the demand side, a combination of increased renovation rate and further improved U-values is necessary. As a possible solution, today's renovation rate from 0.45% (Elsland et al., 2014) should be increased to 1% and furthermore increased linearly to 2% in 2030. This correlates with an average renovation rate of 1.5% in the period 2015-2030. Additionally the calculated cost-optimality U-values need to be further strengthened in average by 11% for new buildings and by 10% for existing buildings to be refurbished. In addition, the heat/cold bridge factors need be reduced from currently about 0.1 W/(m²*K) in new buildings and 0.15 W/(m²*K) in existing buildings to 0.05 W/(m²*K) and 0.1 W/(m²*K) respectively. In warm regions, this improvement of the heat bridge factor can already be sufficient for achieving the needed emission reduction without further improving the U-values. An example to reach the more ambitious standards is presented in the following tables.

Table 11. Example of a possible U-value combination for new constructions in order to reach climate targets as defined in the INDC in case that the renovation rate can be increased to 2% until 2030

Component	Unit	Heat bridge factor	Hot	Cooling-based	Moderate	Rather cold	Medium cold	Cold
Roof	W/(m²*K)	0.05	0.24	0.20	0.18	0.14	0.14	0.12
Façade	W/(m²*K)	0.05	0.32	0.26	0.25	0.18	0.20	0.16
Windows	W/(m²*K)	0.05	1.60	1.60	1.40	1.00	1.00	1.00
Ground	W/(m²*K)	0.05	0.52	0.41	0.39	0.28	0.30	0.26

[4] Consider that this mix just represents the space heating energy consumption. Hot water generation and cooking as other heating uses are excluded
[5] From a technical point of view, traditional biomass is not a renewable source as usually, it is not recultivated orderly and therefore the emission factor should not be assumed as zero. However, in national greeenhouse gas inventories, it is usually accounted as zero

Table 12. Example of a possible U-value combination for refurbishments in order to reach climate targets as defined in the INDC in case that the renovation rate can be increased to 2% until 2030

Component	Unit	Heat bridge factor	Hot	Cooling-based	Moderate	Rather cold	Medium cold	Cold
Roof	W/(m²*K)	0.1	0.25	0.20	0.20	0.15	0.16	0.13
Façade	W/(m²*K)	0.1	0.35	0.28	0.27	0.20	0.20	0.17
Windows	W/(m²*K)	0.1	1.80	1.45	1.10	1.00	1.00	1.00
Ground	W/(m²*K)	0.1	0.51	0.41	0.39	0.30	0.30	0.25

Especially in the cold regions of Turkey it might be complicated to reach climate targets just by further improving U-values and avoiding heat/cold bridges. In addition also more ambitious HVAC systems such as ventilation systems with heat recovery or renewable heating systems such as heat pumps or sustainable biomass boilers could facilitate reaching these standards. Especially the use of ventilation systems with heat recovery could complement the quite ambitious U-value requirements in order to avoid moisture problems and thus increase acceptance in the population and increase the indoor climate.

Figure 39 shows the development of the residential emissions from space heating and space cooling assuming the BAU building stock development as described in chapter 4 and applying the improved U-values, cold bridge factors as well as increased renovation rate. The red horizontal line represents the needed emission benchmark for reaching the climate target as defined in Turkey's INDC. In this context, the ~16.1 Mt_{CO2e} emission target is equivalent to a 21% reduction of the BAU emission path leading to 20.4 Mt_{CO2e} in 2030.

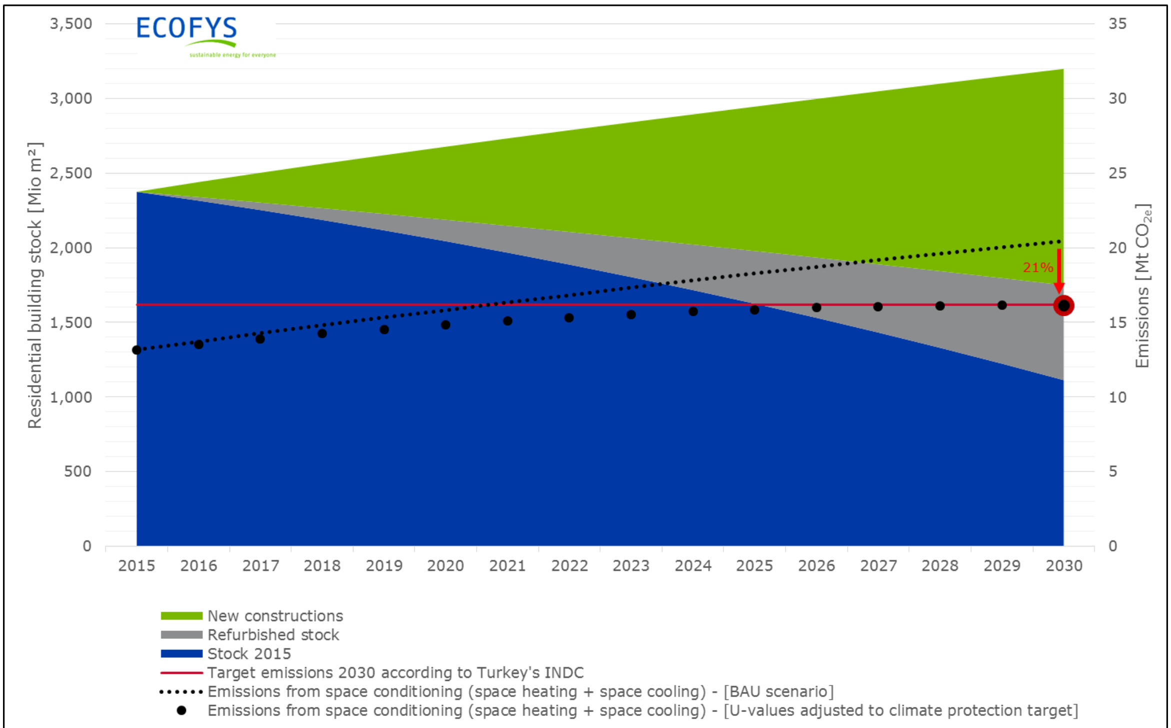

Figure 39. Illustration of the building stock and emission development from space heating and space cooling assuming an increase of the renovation rate from 1% in 2015 to 2% in 2030 and 11% more ambitious U-values for new constructions and 10% for renovations compared to CO-levels

6 Overview and comparison of results

This chapter contains an overview of the calculated results of the study. For this purpose the following figures show for each analysed building element (roof, wall, windows and floor) the identified U-values for each of the six climate regions, construction type (new buildings and renovations) as well as according to TS825 U-value requirements, cost-optimality methodology and for reaching the climate protection target as defined in Turkey's INDC.

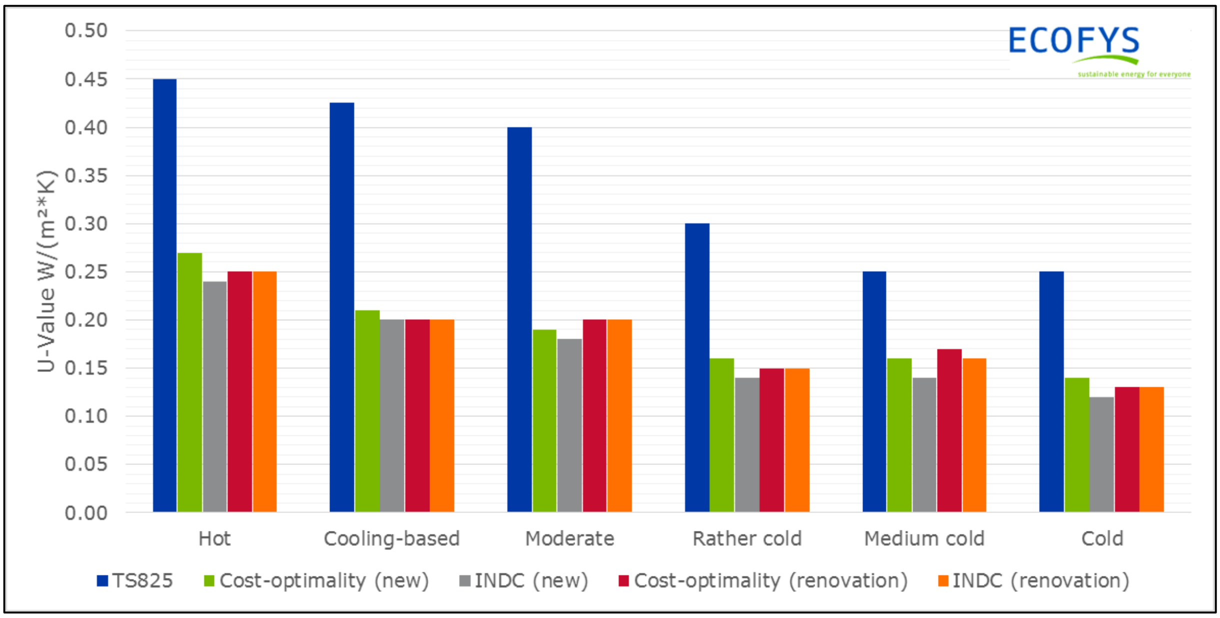

Figure 40. U-value results for roofs in new and existing buildings undergoing a major renovation according to cost-optimality and achievement of climate targets as defined in Turkey INDC for all six climate regions as used in this report

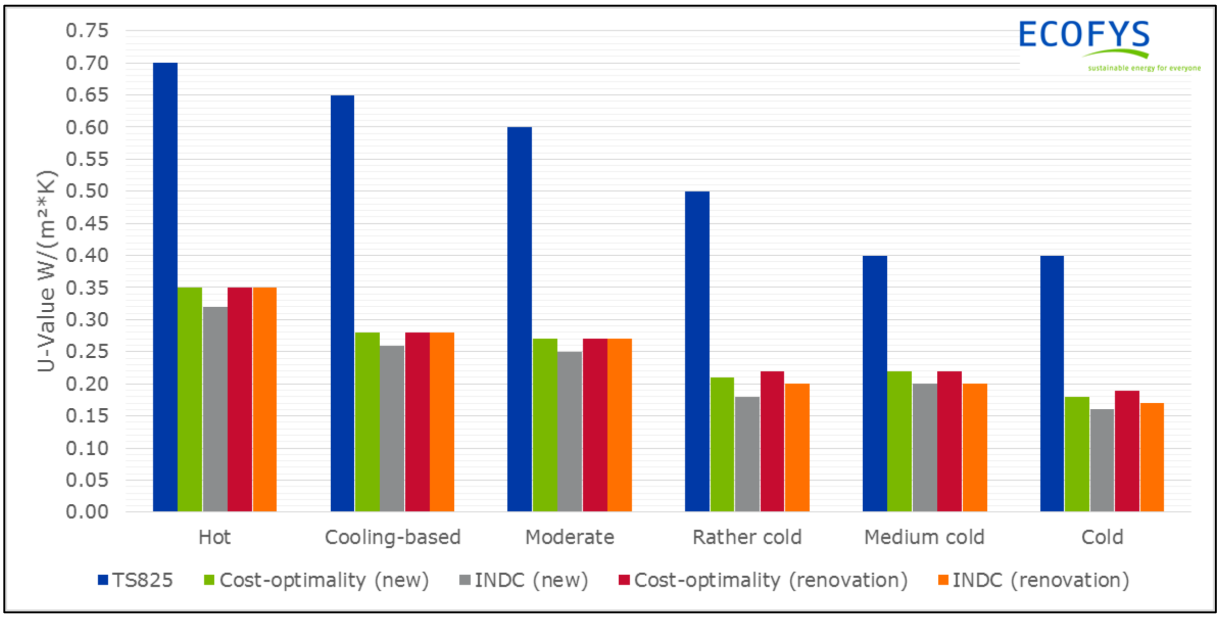

Figure 41. U-value results for façades in new and existing buildings undergoing a major renovation according to cost-optimality and achievement of climate targets as defined in Turkey INDC for all six climate regions as used in this report

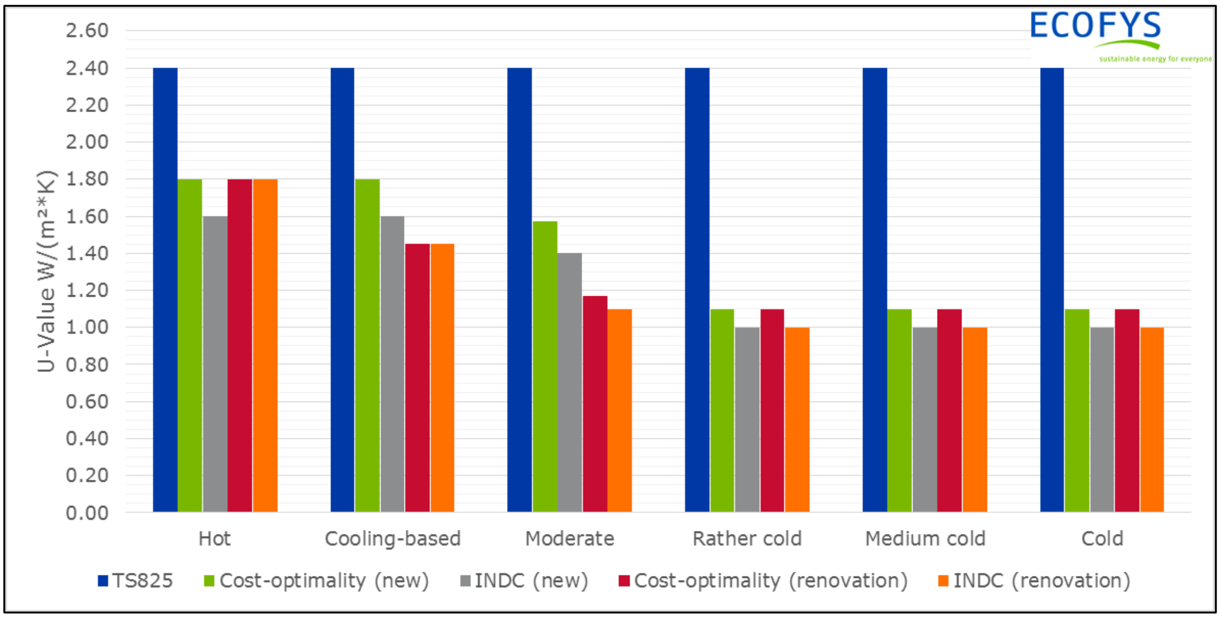

Figure 42. U-value results for windows in new and existing buildings undergoing a major renovation according to cost-optimality and achievement of climate targets as defined in Turkey INDC for all six climate regions as used in this report

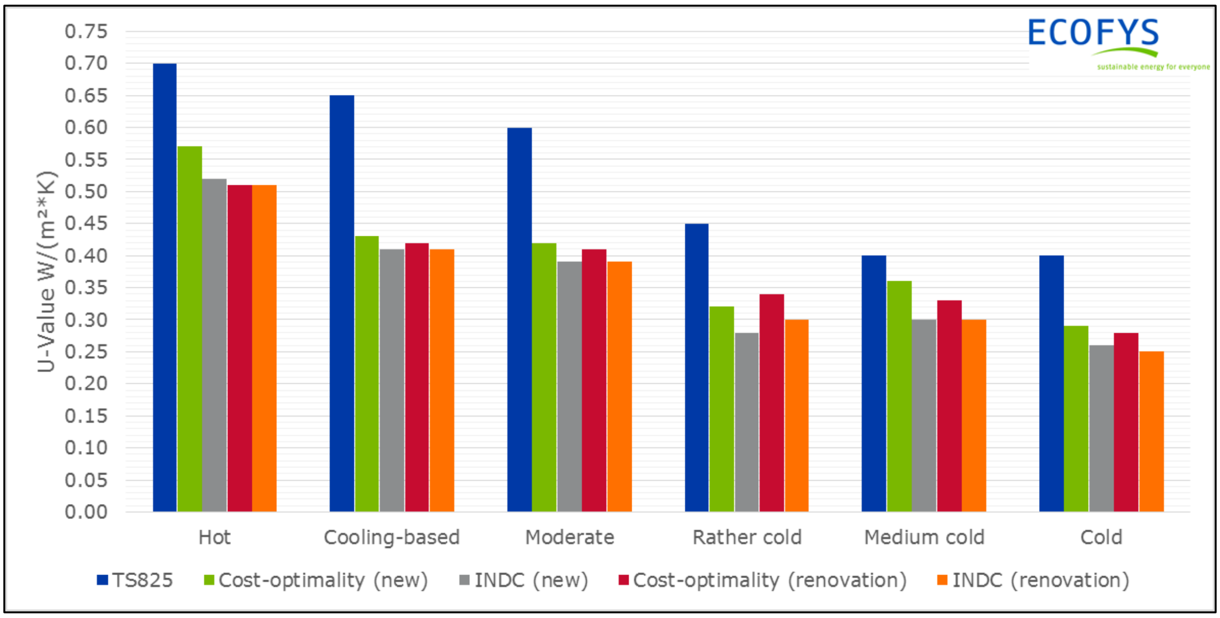

Figure 43. U-value results for ground plates in new and existing buildings undergoing a major renovation according to cost-optimality and achievement of climate targets as defined in Turkey INDC for all six climate regions as used in this report

Based on the identified U-values, the following primary energy demands for space heating and space cooling result. For calculating the primary energy demand for space heating and space cooling, primary energy factors of 1.0 for gas and 2.36 for electricity have been used (Ganiç and Yılmaz, 2014; Mangan and Oral, 2016a). For the energy demand calculations according to TS825, the same calculation parameters have been used as also for the cost-optimality calculations (see ANNEX 2 & 3). It should be considered that these parameters can differ from those defined in TS825.

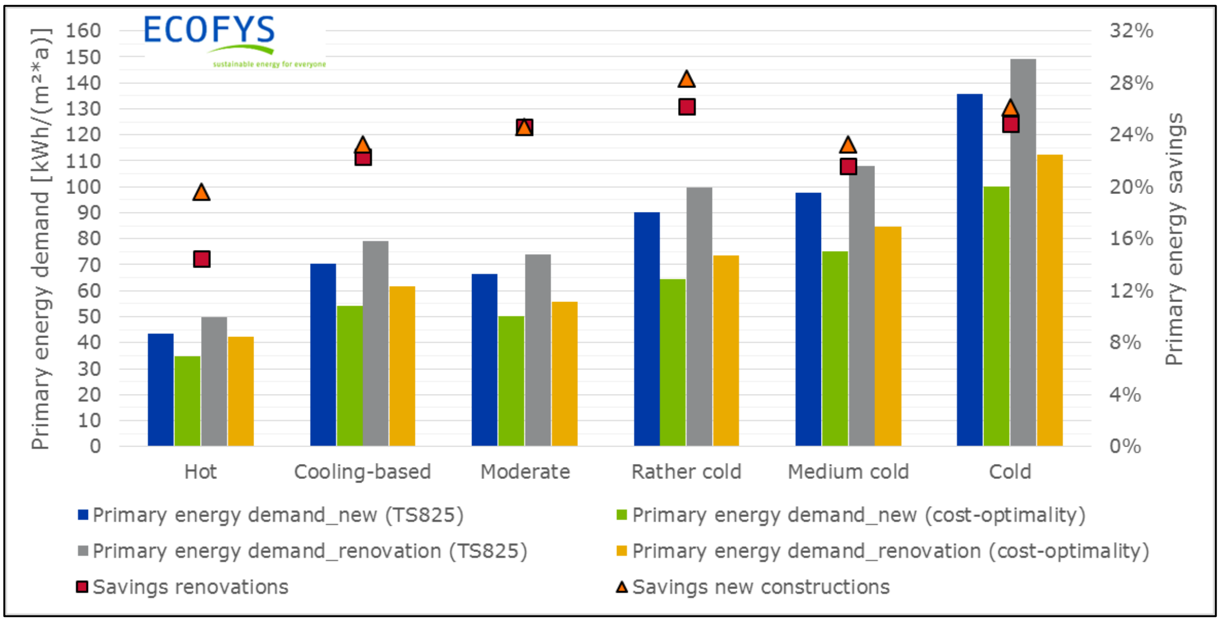

Figure 44. Primary energy demands of new and existing buildings undergoing a major renovation according to the current building code TS825 and cost-optimality calculations for all six climate regions as used in this report

Table 13 presents the calculated specific primary energy demands for space heating and space cooling and resulting emissions for new buildings adjusted to the six climate regions.

Table 13. Overview of the calculated specific primary energy demands for space heating and space cooling and resulting emissions for new buildings adjusted to the six climate regions as used in this report

Component	Unit	Hot	Cooling-based	Moderate	Rather cold	Medium cold	Cold
Primary energy demand (TS825)	kWh/(m²*a)	43.4	70.6	66.5	90.2	97.9	135.6
Primary energy demand (cost-optimality)	kWh/(m²*a)	34.9	54.2	50.1	64.7	75.1	100.2
Primary energy demand (INDC)	kWh/(m²*a)	32.4	50.1	46.3	60.2	70.2	94.0
CO_2-equivalent (TS825)	kg CO_{2e} / (m²*a)	8.2	12.2	10.9	14.2	15.1	20.6
CO_2-equivalent (cost-optimality)	kg CO_{2e} / (m²*a)	6.9	9.6	8.4	10.3	11.7	15.3
CO_2-equivalent (INDC)	kg CO_{2e} / (m²*a)	6.5	9.0	7.8	9.6	10.9	14.3

As can be seen in Table 13, the primary energy saving potential in the cold region by moving from TS825 level to cost-optimal level is 135.6 kWh/(m²*a) – 100.2 kWh/(m²*a) = 35.4 kWh/(m²*a). As an example, applying this reduction potential to a 1,000m² building would lead to a reduction potential of 35.4 kWh/(m²*a) * 1,000m² = 35.4 MWh/a or a mitigation potential of 5.3 t_{CO2e}/a.

Table 14 presents the calculated specific primary energy demands for space heating and space cooling and resulting emissions for existing buildings to be renovated adjusted to the six climate regions as used in this report.

Table 14. Overview of the calculated specific primary energy demands for space heating and space cooling and resulting emissions for existing buildings to be renovated adjusted to the six climate regions as used in this report

Component	Unit	Hot	Cooling-based	Moderate	Rather cold	Medium cold	Cold
Primary energy demand (TS825)	kWh/(m²*a)	49.7	79.2	73.9	99.8	108.2	149.4
Primary energy demand (cost-optimality)	kWh/(m²*a)	42.5	61.5	55.7	73.7	84.8	112.2
Primary energy demand (INDC)	kWh/(m²*a)	38.9	57.0	51.4	69.0	79.5	106.4
CO_2-equivalent (TS825)	kg CO_{2e} / (m²*a)	9.3	13.2	11.6	14.8	15.7	21.3
CO_2-equivalent (cost-optimality)	kg CO_{2e} / (m²*a)	8.3	10.8	9.1	11.2	12.5	16.1
CO_2-equivalent (INDC)	kg CO_{2e} / (m²*a)	7.6	10.0	8.4	10.4	11.7	15.2

7 Conclusions

In the study, we have calculated cost-optimal U-values for roofs, walls, windows and floors in residential buildings in Turkey and calculated the resulting energy demand and emissions. These values have been compared with the Business-as-Usual (BAU) path until 2050 in order to identify the energy saving potential and with a path that is necessary in order to reach Turkey's climate protection target for the year 2030.

The results of the analysis show that the U-values as derived for Turkey from the cost optimality methodology (which aims at achieving the lowest life cycle costs), are significantly more ambitious than current requirements and at the same time suitable to support reaching this climate protection target. This means that climate protection and cost-optimality are not contradictory but can be well combined. However, to reach the climate targets, it requires further strengthening of the U-values by ~10% towards 2030 compared to today's cost-optimality levels. As energy prices are expected to further growth in the future it could be possible that the identified necessary 2030 values are likely to be cost-optimal in 2030 as well.

Our cost analysis resulted in relatively low additional investments that are needed to improve the U-values from TS825 to cost-optimal levels. The required additional investments have been calculated to be in a range between 3 and 10€ per m² building floor area, depending on the province and climate, in average at approximately 6.5€.

In residential buildings in warmer parts of Turkey, thermal insulation also reduces the energy demand for cooling. A well balanced package of roof, wall and floor insulation and selection of the right window with suitable U-values as well as g-values results in a significant and cost-effective reduction of energy demand for space heating and cooling. Recommended maximum U-values resulting from the analyses based on cost-optimality and fitting climate protection targets are significantly more ambitious than current requirements according to TS825, representing a significant potential for energy and emission reductions. We calculated an energy saving potential between the BAU and the cost-optimality scenario of ~7% by 2023, 14% by 2030, 21% by 2040 and 28% by 2050.

It should be noted that for reaching climate targets, U-value requirements should be strengthened rather sooner than later to avoid lock-in effects or capital intense upgrades of building envelopes before the end of their technical life-time.

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ANNEX 1: Heating and cooling degree days per Turkish province

Heating degree days (HDD)

According to the ASHRAE-method, the HDDs are defined as.

HDD = (18.3°C - Tm) if Tm is lower than or equal to 18.3°C in a specific hour of the year

HDD = 0 if Tm is higher than 18.3 °C

where Tm is the mean ((T_{min} + T_{max})/ 2) outdoor temperature over a period of the day of which the specific hour is a part.

Calculations are executed on an hourly basis, added up to a day, a calendar month - and subsequently to a year. 18.3 °C corresponds to 65 Fahrenheit.

Cooling Degree days (CDD)

According to the ASHRAE-method, the CDDs are defined as.

CDD = (Tm- 18.3°C) if Tm is higher than or equal to 18.3 °C in a specific hour of the year

CDD = 0 if Tm is lower than 18.3 °C in a specific hour of the year

where Tm is the mean ((T_{min} + T_{max})/ 2) outdoor temperature over a period of the day of which the specific hour is a part.

Calculations are executed on an hourly basis, added up to a day, a calendar month - and subsequently to a year. 18.3 °C corresponds to 65 Fahrenheit.

The following table presents heating and cooling degree days of 81 Turkish provinces according to the methodologies that have been described on basis of hourly climate data (long term averages) from METEONORM (http://www.meteonorm.com/en).

Province	HDD [Kd/a]	CDD [Kd/a]	Climate region as used in this report	Region #
Adana	968	1350	Hot	1
Adiyaman	2445	932	Rather cold	4
Afyonkarahisar	2494	497	Rather cold	4
Ağrı	4082	175	Cold	6
Amasya	2686	358	Rather cold	4
Ankara	2793	476	Rather cold	4
Antalya	859	1317	Hot	1
Artvin	2111	396	Rather cold	4
Aydın	1382	1162	Cooling-based	2
Balıkesir	2030	670	Rather cold	4
Bilecik	2679	399	Rather cold	4
Bingöl	3407	554	Medium cold	5
Bitlis	3300	326	Medium cold	5
Bolu	2804	241	Rather cold	4
Burdur	2547	471	Rather cold	4
Bursa	1869	703	Moderate	3
Çanakkale	1820	784	Moderate	3
Çankırı	2910	376	Rather cold	4
Çorum	2916	323	Rather cold	4
Denizli	1556	1179	Cooling-based	2
Diyarbakır	2133	1277	Rather cold	4
Edirne	2130	742	Rather cold	4
Elazığ	2944	697	Rather cold	4
Erzincan	3195	409	Medium cold	5
Erzurum	4957	86	Cold	6
Eskişehir	2837	357	Rather cold	4
Gaziantep	1902	1215	Cooling-based	2
Giresun	1733	542	Moderate	3
Gümüşhane	3221	405	Medium cold	5
Hakkari	3198	327	Medium cold	5
Hatay	761	1522	Hot	1
Isparta	2556	469	Rather cold	4
Mersin	955	1381	Hot	1
İstanbul	1667	676	Moderate	3
İzmir	1500	1061	Cooling-based	2
Kars	4843	54	Cold	6
Kastamonu	3057	333	Medium cold	5
Kayseri	3062	330	Medium cold	5
Kırklareli	2187	628	Rather cold	4
Kırşehir	2746	536	Rather cold	4
Kocaeli	1692	791	Moderate	3
Konya	2774	534	Rather cold	4
Kütahya	2679	423	Rather cold	4
Malatya	2535	887	Rather cold	4
Manisa	1534	1069	Cooling-based	2
Kahramanmaraş	1835	1254	Cooling-based	2
Mardin	2280	1135	Rather cold	4
Muğla	1858	908	Moderate	3
Muş	3131	671	Medium cold	5
Nevşehir	3035	362	Medium cold	5

Niğde	2970	385	Rather cold	4
Ordu	1834	524	Moderate	3
Rize	1734	556	Moderate	3
Sakarya	1644	818	Moderate	3
Samsun	1807	525	Moderate	3
Siirt	2365	1082	Rather cold	4
Sinop	1775	553	Moderate	3
Sivas	3366	265	Medium cold	5
Tekirdağ	2010	630	Rather cold	4
Tokat	2804	346	Rather cold	4
Trabzon	1614	533	Moderate	3
Tunceli	3113	564	Medium cold	5
Şanlıurfa	1800	1377	Cooling-based	2
Uşak	2431	529	Rather cold	4
Van	3384	260	Medium cold	5
Yozgat	3277	305	Medium cold	5
Zonguldak	1799	401	Moderate	3
Aksaray	2796	498	Rather cold	4
Bayburt	4589	117	Cold	6
Karaman	1848	722	Moderate	3
Kırıkkale	2834	452	Rather cold	4
Batman	1827	1492	Cooling-based	2
Şırnak	2954	451	Rather cold	4
Bartın	1899	414	Moderate	3
Ardahan	4842	52	Cold	6
Iğdır	2858	594	Rather cold	4
Yalova	1703	771	Moderate	3
Karabük	2888	293	Rather cold	4
Kilis	1784	1260	Cooling-based	2
Osmaniye	1809	1237	Cooling-based	2
Düzce	1808	548	Moderate	3

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ANNEX 2: Calculation parameters – New constructions

Calculation parameters - New constructions													
City		**Antalya**	**Izmir**	**Gaziantep**	**Mugla**	**Istanbul**	**Bursa**	**Ankara**	**Nigde**	**Sivas**	**Agri**	**Kars**	**Erzurum**
Reference building													
Building Type*		sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new
Net floor area	m²	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440
Cold bridge factor	W/(m²*K)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Space heating system		Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG
Space cooling system		With	With	With	With	With	With	With	With	With	With	With	With
Space heating efficiency (first year/last year)	%	95/95	95/95	95/95	95/95	95/95	95/95	95/95	95/95	95/95	95/95	95/95	95/95
Space cooling efficiency (first year/last year)	%	450/450	450/450	450/450	450/450	450/450	450/450	450/450	450/450	450/450	450/450	450/450	450/450
Mechanical ventilation	[1/h]	-	-	-	-	-	-	-	-	-	-	-	-
Free ventilation (windows)	[1/h]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Infiltration	[1/h]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Economic parameters													
Gas price start year	€/kWh	0.039	0.039	0.033	0.036	0.041	0.039	0.042	0.041	0.033	0.034	0.034	0.039
Electricity price start year	€/kWh	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Energy price development		Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Real annual gas price increase	%/a	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Real annual electricity price increase	%/a	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Interest rate (real)	%/a	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
Calculation period	a	30	30	30	30	30	30	30	30	30	30	30	30
Lifetimes													
Gas Boiler	a	20	20	20	20	20	20	20	20	20	20	20	20
Air conditioning system	a	20	20	20	20	20	20	20	20	20	20	20	20
Insulation (Exterior wall)	a	30	30	30	30	30	30	30	30	30	30	30	30
Insulation (Roof)	a	30	30	30	30	30	30	30	30	30	30	30	30
Insulation (Ground)	a	30	30	30	30	30	30	30	30	30	30	30	30
Windows	a	30	30	30	30	30	30	30	30	30	30	30	30
Climate Parameters													
Average temperature	°C	19.40	16.95	16.29	15.58	15.52	15.01	11.85	11.09	9.71	7.42	5.02	4.93
Min. Temperature	°C	3	-4	-6	-6	-3	-6	-14	-15	-19	-21	-25	-30
Max. Temperature	°C	41	40	41	39	33	38	37	35	37	32	31	34
Duration of Heating period	d	123	163	168	180	182	182	209	199	220	238	268	261
Duration of cooling period	d	167	150	155	133	117	125	103	105	77	71	35	42
Global Radiation													
North	kWh/(m²*a)	474	470	468	456	429	431	451	475	454	467	469	462
East	kWh/(m²*a)	1,036	1,041	1,142	928	842	851	874	1,218	975	974	961	937
South	kWh/(m²*a)	1,260	1,238	1,380	1,000	980	985	1,048	1,508	1,190	1,164	1,186	1,130
West	kWh/(m²*a)	1,042	1,041	1,143	917	821	819	881	1,185	972	970	938	925
Horizontal	kWh/(m²*a)	1,747	1,732	1,903	1,545	1,370	1,369	1,424	1,965	1,573	1,568	1,489	1,498
Current requirements	**Unit**												
U-value roof	W/(m²*K)	0.45	0.45	0.40	0.40	0.40	0.40	0.30	0.30	0.25	0.25	0.25	0.25
U-value facade	W/(m²*K)	0.70	0.70	0.60	0.60	0.60	0.60	0.50	0.50	0.40	0.40	0.40	0.40
U-value windows	W/(m²*K)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
U-value ground	W/(m²*K)	0.70	0.70	0.60	0.60	0.60	0.60	0.45	0.45	0.40	0.40	0.40	0.40

* sMFH_new: small Multi-familiy building (new)

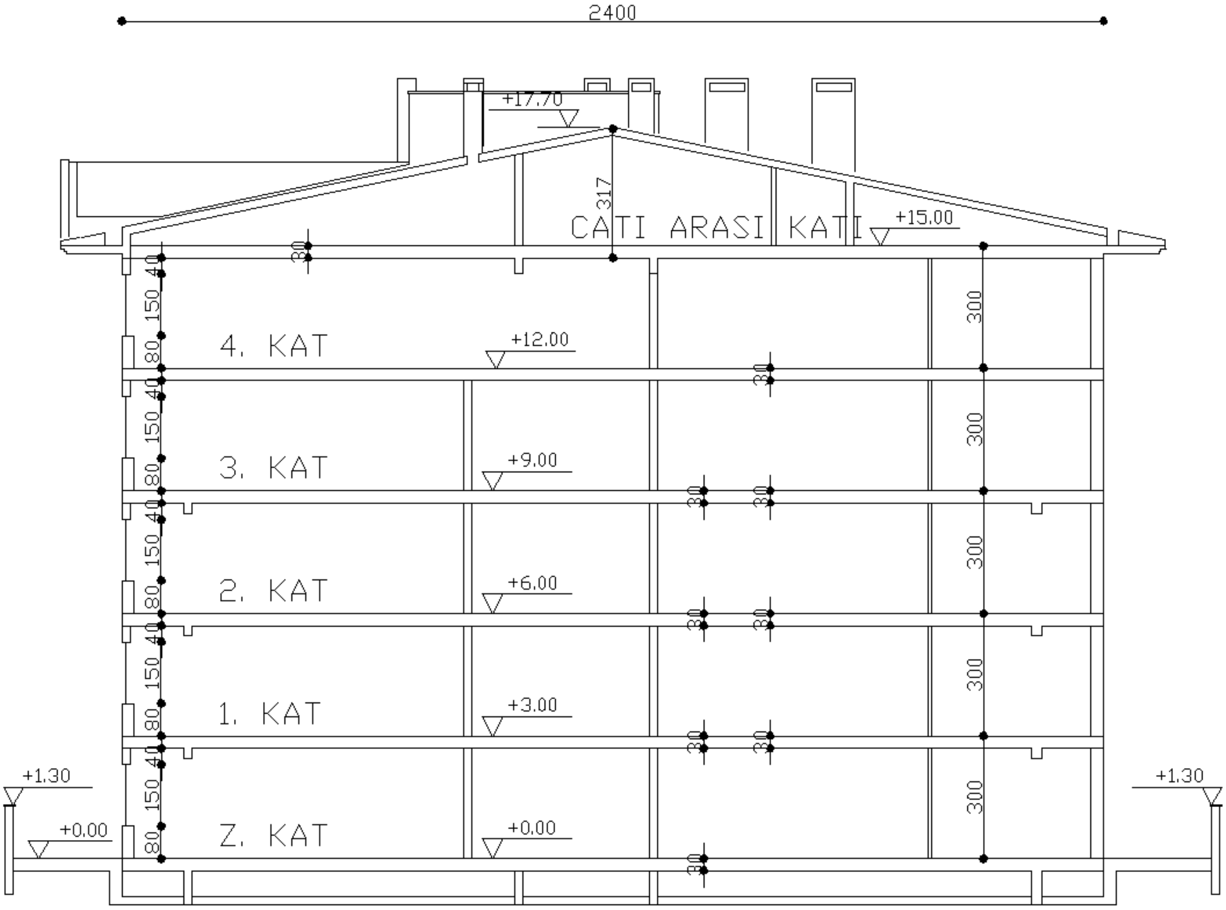
ANNEX 3: Calculation parameters – Renovations

Calculation parameters - Renovations													
City		**Antalya**	**Izmir**	**Gaziantep**	**Mugla**	**Istanbul**	**Bursa**	**Ankara**	**Nigde**	**Sivas**	**Agri**	**Kars**	**Erzurum**
Reference building													
Building Type*		sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new	sMFH_new
Net floor area	m²	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440
Cold bridge factor	W/(m²*K)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Space heating system		Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG	Gas Boiler - NG
Space cooling system		With	With	With	With	With	With	With	With	With	With	With	With
Space heating efficiency (first year/last year)	%	80/95	80/95	80/95	80/95	80/95	80/95	80/95	80/95	80/95	80/95	80/95	80/95
Space cooling efficiency (first year/last year)	%	250/400	250/400	250/400	250/400	250/400	250/400	250/400	250/400	250/400	250/400	250/400	250/400
Mechanical ventilation	[1/h]	-	-	-	-	-	-	-	-	-	-	-	-
Free ventilation (windows)	[1/h]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Infiltration	[1/h]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Economic parameters													
Gas price start year	€/kWh	0.039	0.039	0.033	0.036	0.041	0.039	0.042	0.041	0.033	0.034	0.034	0.039
Electricity price start year	€/kWh	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Energy price development		Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Real annual gas price increase	%/a	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Real annual electricity price increase	%/a	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Interest rate (real)	%/a	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
Calculation period	a	30	30	30	30	30	30	30	30	30	30	30	30
Lifetimes													
Gas Boiler	a	20	20	20	20	20	20	20	20	20	20	20	20
Air conditioning system	a	20	20	20	20	20	20	20	20	20	20	20	20
Insulation (Exterior wall)	a	30	30	30	30	30	30	30	30	30	30	30	30
Insulation (Roof)	a	30	30	30	30	30	30	30	30	30	30	30	30
Insulation (Ground)	a	30	30	30	30	30	30	30	30	30	30	30	30
Windows	a	30	30	30	30	30	30	30	30	30	30	30	30
Climate Parameters													
Average temperature	°C	19.40	16.95	16.29	15.58	15.52	15.01	11.85	11.09	9.71	7.42	5.02	4.93
Min. Temperature	°C	3	-4	-6	-6	-3	-6	-14	-15	-19	-21	-25	-30
Max. Temperature	°C	41	40	41	39	33	38	37	35	37	32	31	34
Duration of Heating period	d	125	164	167	179	182	183	211	202	224	241	271	264
Duration of cooling period	d	166	148	156	134	117	122	100	101	74	67	32	39
Global Radiation													
North	kWh/(m²*a)	474	470	468	456	429	431	451	475	454	467	469	462
East	kWh/(m²*a)	1,036	1,041	1,142	928	842	851	874	1,218	975	974	961	937
South	kWh/(m²*a)	1,260	1,238	1,380	1,000	980	985	1,048	1,508	1,190	1,164	1,186	1,130
West	kWh/(m²*a)	1,042	1,041	1,143	917	821	819	881	1,185	972	970	938	925
Horizontal	kWh/(m²*a)	1,747	1,732	1,903	1,545	1,370	1,369	1,424	1,965	1,573	1,568	1,489	1,498

* sMFH_new: small Multi-familiy building (new)

ANNEX 4: Reference building

Parameter	Unit	Reference building –
Construction type		Multi-family house
Number of dwellings		10
Useful floor area (A-gross)	[m2]	1440
Clear room height	[m]	2,70
Storeys		5
Ratio Width/Depth		2
Width	[m]	24
Depth	[m]	12
Volume (V-gross)	[m3]	4320
Ratio A/V	[ ]	0,33
Thickness floor slab	[m]	0,30
Ground floor	[m2]	288
Total gross wall area (including windows and attached areas)	[m2]	1080
Outer wall (excluding windows)	[m2]	918
Thereof Wall (North)	[m2]	153
Thereof Wall (East)	[m2]	306
Thereof Wall (South)	[m2]	153
Thereof Wall (West)	[m2]	306
Roof type		pitched
Slope		33 %
Roof area	[m2]	288
Share of total window area (of façade)		15%
Windows (total)	[m2]	162
Windows (North)	[m2]	27
Windows (East)	[m2]	54
Windows (South)	[m2]	27
Windows (West)	[m2]	54
Total outer building shell area	[m2]	1656
Thereof Windows (West)	Ratio of window area to total shell area	0,03
Thereof Windows (South)		0,015
Thereof Windows (East)		0,03
Thereof Windows (North)		0,015
Ratios		
Outer wall (excluding windows) / Useful floor area		0.6375
Outer wall (including windows) / Useful floor area		0.75
Total outer building shell area / Useful floor area		1.15
A/V		0.33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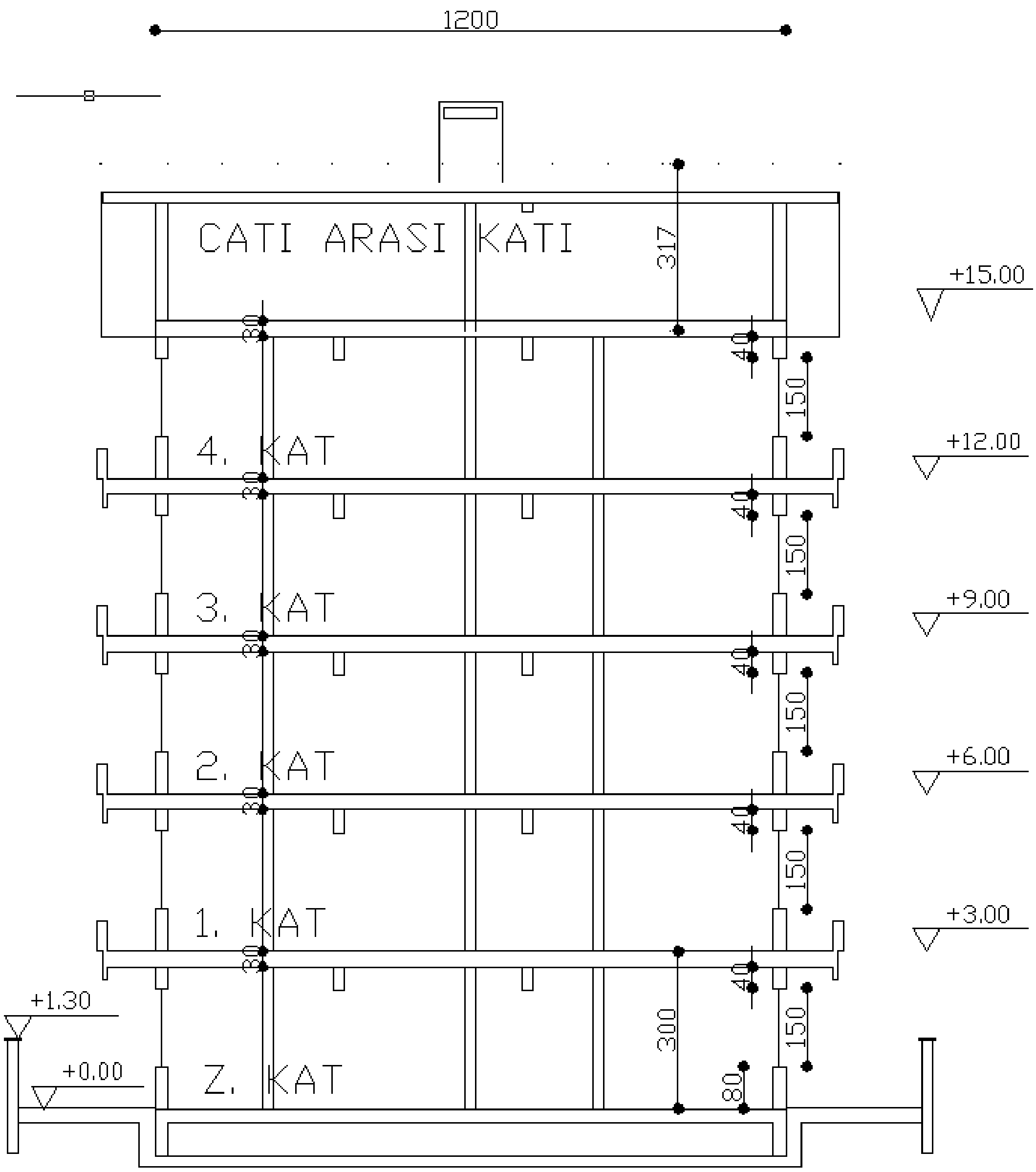
+17.70
317
CATI ARASI KATI
+15.00
4. KAT
+12.00
3. KAT
+9.00
2. KAT
+6.00
1. KAT
+3.00
Z. KAT
+0.00
+1.30
+0.00
+1.30
300
30
40
150
80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CATI ARASI KATI
317
+15.00
4. KAT
+12.00
3. KAT
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+3.00
Z. KAT
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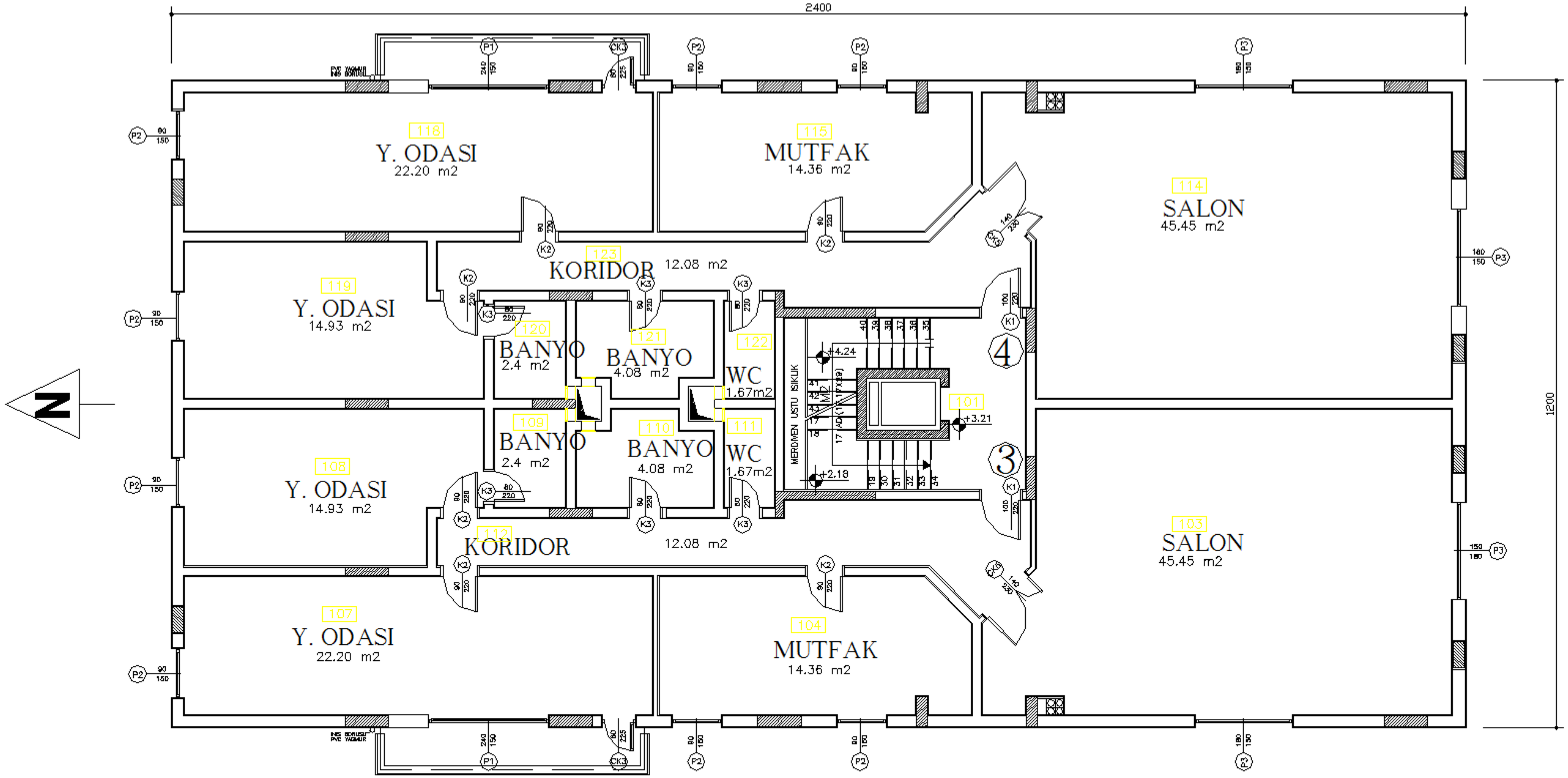
+0.00
300
80
30
40
150


2400
1200
Y. ODASI
22.20 m2
MUTFAK
14.36 m2
SALON
45.45 m2
KORIDOR
12.08 m2
Y. ODASI
14.93 m2
BANYO
2.4 m2
BANYO
4.08 m2
WC
1.67m2
MERDIVEN USTU ISIKLIK
BANYO
2.4 m2
BANYO
4.08 m2
WC
1.67m2
Y. ODASI
14.93 m2
SALON
45.45 m2
KORIDOR
12.08 m2
Y. ODASI
22.20 m2
MUTFAK
14.36 m2
+4.24
+3.21
+2.18
4
3

ANNEX 5: Investment cost assumptions

Insulation costs:

Table 15. Assumed investment costs for insulation (information provided by IZODER using an assumed average conversion rate of 3TL/1€)

		All Regions New Construction & Stock/Renovation[6]			
Energy related fixed costs for insulation **Assumption : €= 3TL (august 2015)**		EPS	XPS	Stone wool	Glass wool
Wall 5 cm	**Cost €/m²**	**14,28**	**15,46**	**19,04**	----
	Market %	80 %	13 %	7 %	0 %
Roof EPS and XPS 8 cm MW 10 cm	**Cost €/m²**	**6,17**	**7,83**	**4,50**	**2,50**
	Market %	5 %	20 %	5 %	70 %
Floor EPS and XPS 5 cm MW 6 cm	**Cost €/m²**	**4,83**	**5,17**	**7,50**	**0,00**
	Market %	5 %	85 %	10 %	0 %
Costs for additional cm of insulation		EPS **€/m²/cm**	XPS **€/m²/cm**	Stone wool **€/m²/cm**	Glass wool **€/m²/cm**
	Wall	**0,53**	**0,77**	**0,93**	
	Roof	**0,53**	**0,83**	**0,33**	**0,13**
	Floor	**0,66**	**0,80**	**1,06**	

Window costs:

Table 16. Assumed investment costs for windows (information provided by IZODER using an assumed average conversion rate of 3TL/1€). The prices comprise costs for glazing, frame and installation

#	Type	U-Value	Costs [€/m²] (excl. VAT)
1	Double Glazing	2.4	76.69
2	Double Glazing	2.3	77.80
3	Double Glazing	2.2	78.91
4	Double Glazing	2.1	80.01
5	Double Glazing	2.0	81.12
6	Double Glazing	1.9	82.22
7	Double Glazing	1.8	83.33
8	Double Glazing	1.7	86.11
9	Double Glazing	1.6	88.89
10	Double Glazing	1.5	91.67
11	Double Glazing	1.4	94.44
12	Double Glazing	1.3	97.22
13	Double Glazing	1.2	100.00
14	Double Glazing	1.1	102.78
15	Triple Glazing	1.0	116.66
16	Triple Glazing	0.9	118.33
17	Triple Glazing	0.8	121.66

[6] The considered costs for wall insulation at renovation are assumed to be 8% higher than the specified values (new construction)

HVAC costs:

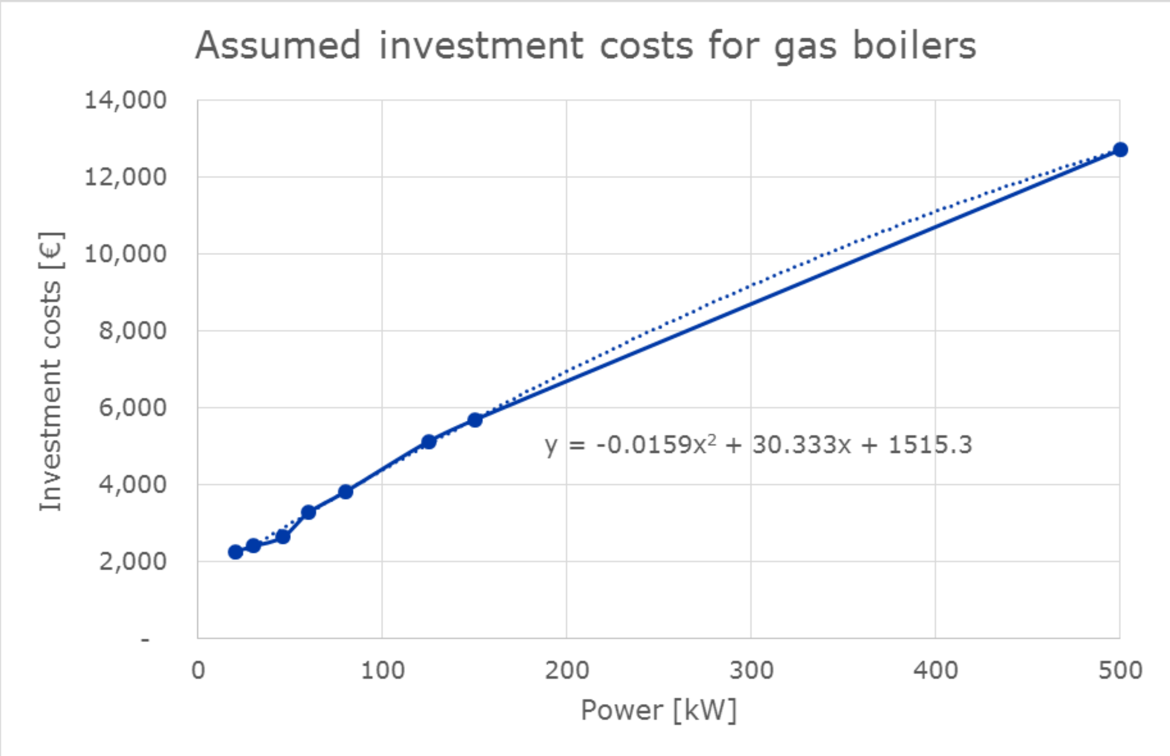


Figure 45. Assumed investment costs for gas boilers (information provided by IZODER using an assumed average conversion rate of 3TL/1€)

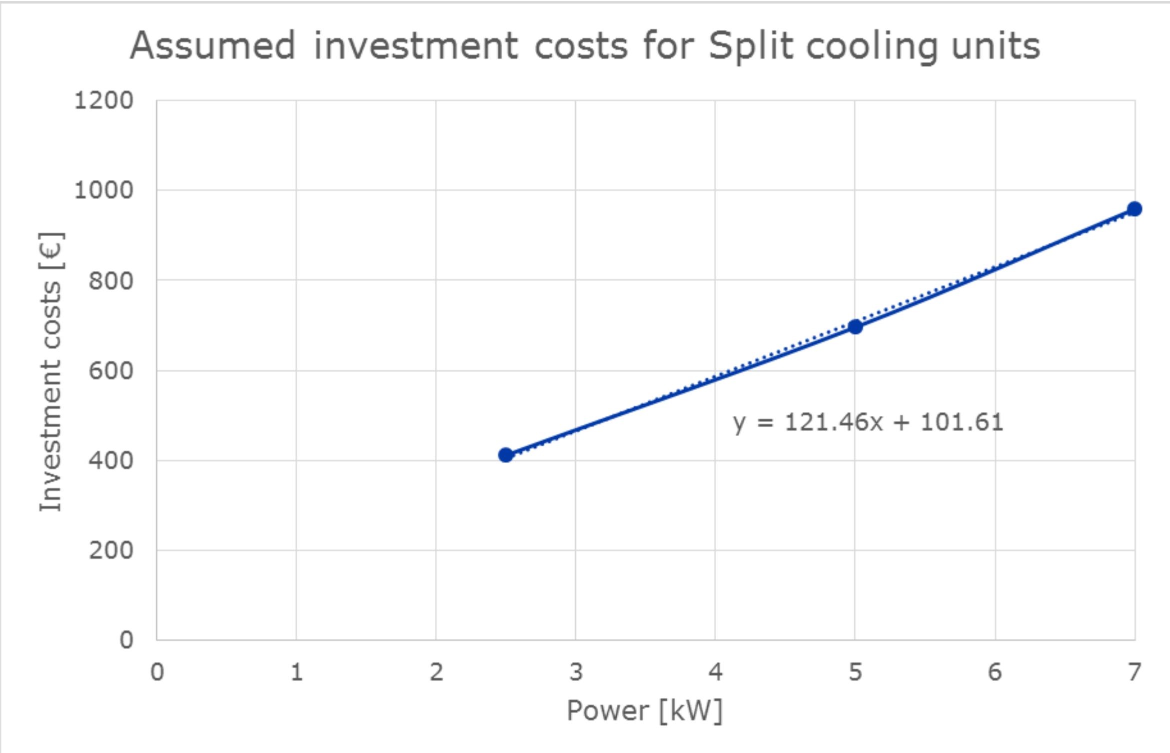


Figure 46. Assumed investment costs for split cooling units (information provided by IZODER using an assumed average conversion rate of 3TL/1€)

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