TURKMENISTAN

NEAR ZERO-ENERGY BUILDINGS

Jan VAN DEN AKKER

2023

TABLE OF CONTENTS

LIST OF BOXES

1. DEVELOPMENT CHALLENGE

1.1 Context and global significance

Country context

The population in Turkmenistan was estimated at 6.25 million[1]. The population growth has been declining from 1.74% in 2016 to 1.5% in 2020. The country is also undergoing a steady shift toward greater urbanization with an urban share of 52.5% (3.167 million)[2]. The rapid expansion of the construction sector in the country for the last 10-15 years has led to increased environmental pressure and negative impact – resource consumption, waste, local air and water pollution, and greenhouse gas emissions (GHGs). The sources of these impacts are varied, including expanded housing sector, rising use of private motor vehicles, expansion of public lighting, and consumption of resources and generation of waste. Ashgabat's population increased from about 524,000 in the year 2000 to about 883,000 in 2022[3]. Most of the country is covered by the sparsely populated Karakum Desert.

Energy and electricity

Turkmenistan possesses one of the world's largest reserves[4] of natural gas and this is also the main export product of the country[5]. Production of natural gas went up from only 1.16 billion cubic meters (bcm) in 1965 to 90 bcm in 1989. Following independence, natural gas extraction fell (see Box 1) as Turkmenistan sought export markets but was limited to existing delivery infrastructure under Russian control[6]. The Trans-Asia pipeline to China opened in 2009, exporting some 30-35 bcm of gas to China annually. The East-West pipeline was completed in December 2015, with the intent of delivering up to 30 bcm of natural gas to the Caspian shore for eventual export through the Southern Corridor gas pipeline system[7]. In 2021, production stood at 79.3 bcm (in 2020, 66 bcm) while consumption was 36.7 bcm (28 bcm in 2020) with exports of 42.6 bcm. Oil is produced from wells in the western lowlands and offshore in the Caspian Sea. The country produced 219 thousand barrels a day in 2021 with consumption standing at 146 thousand barrels a day (140 thousand a day in 2020). Oil reserves are an estimated 600 million barrels[8].

Turkmenistan's power is generated in ten plants, almost solely from natural gas, with 21.18 TWh in 2021 (and 20.1 TWh in 2020, of which almost all from natural gas and 3 GWh from hydropower). With production about 1.5 times consumption (15.09 TWh in 2020), the country is a net exporter to neighbouring countries (about 3.2 TWh)[9]. The installed capacity was 7.4 GW in 2021 (up from 7.0 in 2019). Total production was 3,251 petajoules (PJ) in 2020 of which 67% was exported. Primary supply amounted to 1003 PJ (of which 0.4 PJ biomass. The final energy consumption was 672 PJ in 2020 (see Box 1).

1 Based on Worldometer, extrapolated fromof the latest United Nations data (2020), 2.05 million

2 Up from 2.872 million (50.7%) in 2016

3 https://www.macrotrends.net/cities/22739/ashgabat/population

4 Estimated at between 7.5 to 19 trillion m^3 (tcm). Source www.worldometers.info/gas/turkmenistan-natural-gas and *CAREC Energy Outlook 2030*. There are numerous oil and natural gas fields spread across the country, including the Galkynysh field, which is the world's second-largest natural gas field.

5 Natural gas: 81.4% in 2019. Crude oil and oil products, 10.0%. Turkmenistan Product Exports (2019) Data Source: BACI - HS6

6 *Türkmenistanyň Geografiýasy* (in Turkmen). Ashgabat: Bilim Ministrligi (2010). www.worldometers.info/gas/turkmenistan-natural-gas/

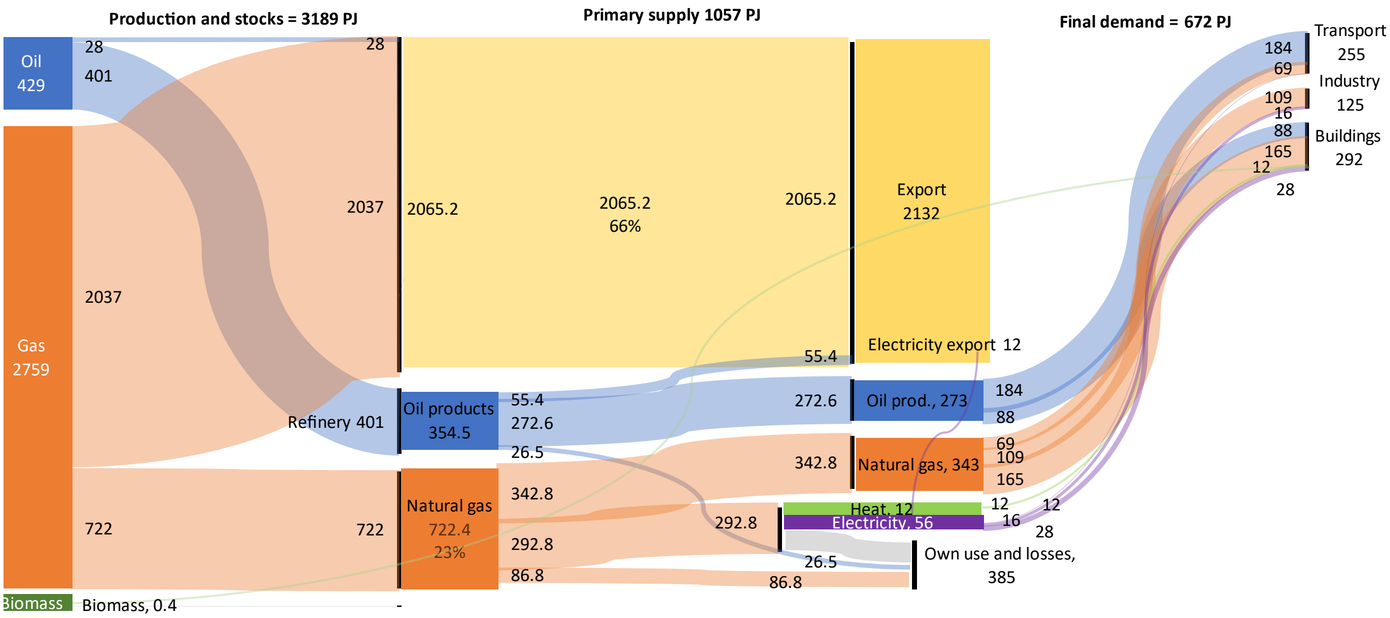
7 The section Azerbaijian-Turkey (South Caucasus pipeline, SCP) began operations in 2020; the Trans-Anatolian pipeline (TANAP) in 2018, and the Transadriatic pipeline (TAP; Turkey-Italy) in 2020. Gas data from bp-stats-review-2022-all-data.xls

8 www.worldometers.info/oil/turkmenistan-oil/#oil-production, based on BP (bp-stats-review-2022-all-data.xls) and US EIA statistics.

9 www.worlddata.info/asia/turkmenistan/energy-consumption.php; and h/ourworldindata.org/grapher/electricity-oil?tab=chart&country=TKM

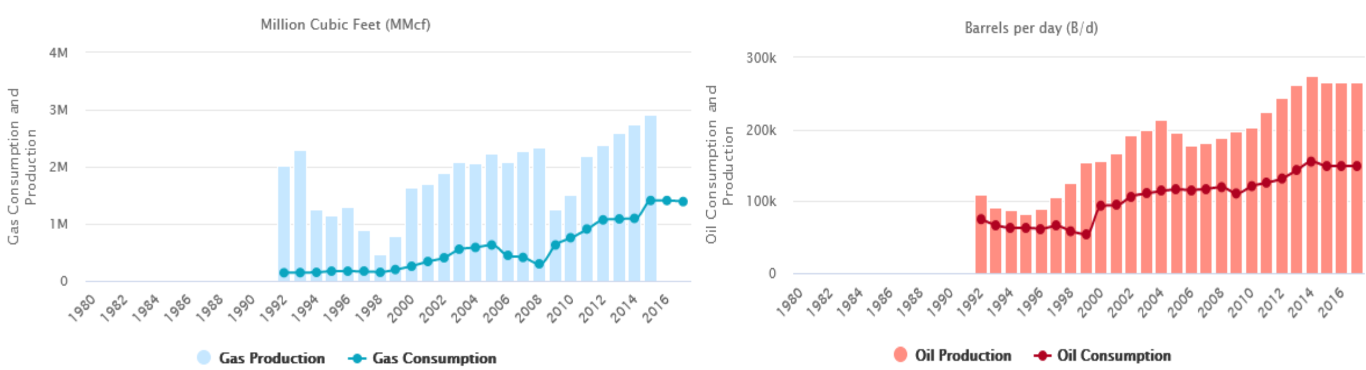
Box 1 Natural gas and oil production and consumption, Turkmenistan

a) Energy production, export and final consumption (2020)



Source: based on data compiled from IEA statistics, BP statistics (websites) and *The value of fast transitioning to a fully sustainable energy system: The case of Turkmenistan,* by Satymov et.al. DOI 10.1109/access .2021.3050817, IEEE.

b) Natural gas and oil production and consumption



Source: worldindata.org

Climate

Greenhouse gas (GHG) emissions from energy were 54.3 million tons of CO_2 ($MtCO_2$) in 2010, 70.9 $MtCO_2$ in 2016 and 94.3 $MtCO_2$ in 2021[10]. The National Strategy on Climate Change the Government of Turkmenistan identifies the housing sector (along with other high GHG emitting sectors) as one of the priority areas for reducing GHG emissions that will help to achieve its commitments within the Paris Agreement.

[10] Source: BP statistics. The Third National Communication (20160 gives a figure of 66.3 $MtCO_2$, of which 85% (56.3 $MtCO_2$) from the energy sector in 2010. Within energy, fugitive emissions (from upstream oil and gas activities) accounted for 36%, buildings (mainly from electricity energy and heating in residential and municipal buildings) 29%, power generation 22% and transport 13%

1.2 Baseline situation

Buildings in the residential sector

Severe climate conditions in Turkmenistan make effective heating and cooling in buildings essential to the well-being of the country's inhabitants. Temperatures range from an average of -6°C in north-eastern Turkmenistan in January to maximum temperatures of 48-50°C in the Central and Southeast Karakum in the summer (see Box 11) or info on average temperatures). For this reason, cooling issues in the housing stock are as important as heating issues.

One- and two-story low-rise cottages (private homes) form about 33% of building stock; often row houses that use some traditional design knowledge about maintaining a comfortable indoor climate. Low-rise cottages often use electric heating and electric air conditioners; although some of these homes, particularly in Ashgabat, receive heat from district heating systems. These buildings have largely been constructed at the initiative of the occupants, and for the very small market segment of residential villas, local companies handle design and construction.

Multi-story buildings provided two-thirds of buildings stock, with 21% three-storey, 36% four-storey, 7.5% five-six storey and the remaining 2.5%, 9-12 storey buildings ([11]. Many multi-story apartment buildings were built between 1960 and 1991 in "micro-districts," which are often owned by municipalities. Construction techniques include low-rise brick and ceramic construction with a plaster façade and no roof or external wall insulation, but they also include high-rise panel construction or reinforced concrete buildings (often based on design templates from other then-Soviet republics). Many of these apartments are heated with district heating (often supplemented by electric heaters where heat delivery is unreliable) and cooled with electric air conditioning units. This group of buildings represent a large potential for future refurbishment and reconstruction.

Urban population growth has triggered a construction boom, the construction of many major residential building projects and the expansion of associated public buildings and related infrastructure. Contemporary, multi-unit, high-rise apartment buildings have been built in the past two decades. These buildings have a reinforced concrete structure and use mineral wool insulation and a marble façade to reduce heat loss. They rely largely on free-standing, building-level, or multi-building gas boilers for heat and hot water, and building-level or multi-building chillers for cooling. The buildings are often constructed by government entities and then apartments are sold individually to prospective dwellers.

Energy demand forecasts

The report *CAREC Energy Outlook 2030* (ADB, 2020) forecasts total final energy demand to increase from the current 16 million tons of oil equivalent (Mtoe)[12] to between 27.8 Mtoe and 30.1 Mtoe by 2030 (depending on the level of energy efficiency improvements adopted). Natural gas will remain Turkmenistan's main source of primary energy supply and continue to dominate the power generation mix.

In the CAREC scenarios, the roll-out of solar plants and wind energy may provide between 2-3% and 1-2% in the power generation mix by 2030. Turkmenistan has tremendous potential for harnessing solar energy. With more than 300 sunny days annually and with an average annual intensity of solar radiation ranging between 700–800 watts per square meter (W/m_2), the total technical potential of solar energy amounts to 655 GW. the country has not yet developed any large-scale solar photovoltaic (PV) projects. However, companies specializing in off-grid systems have entered the market, and some remote regions are using solar installations as a substitute for diesel generators. The development of solar PV (and solar thermal) represents a significant technology transfer opportunity. Because the introduction of solar energy would mitigate the country's reliance on natural gas-powered generation, it would also have a large impact on decarbonization efforts[13].

11 Estimates made by EERB project (implemented during 2012-2018)

12 Equivalent to 672 PJ, see Box 1

13 The technical potential of wind power in Turkmenistan is estimated at 10 GW of capacity. This potential remains unexploited as the country has no large-scale wind power projects to date. Source*: CAREC Energy Outlook 2030*. CAREC: Central Asian Regional Energy

Energy efficiency

Turkmenistan has considerable potential for energy savings through the implementation of energy efficiency measures on the consumption side. Based on existing inefficiencies and baseline consumption figures, the residential and services sectors were identified as a high priority. As shown in Box 1, the residential and services sectors (using energy to heat and cool buildings and for appliances) accounted for around 43% of the total final energy consumption in Turkmenistan (in 2020).

During 2011-20, UNDP with several Turkmen national partners, led by the state utility Turkmengaz, implemented the project "Improving Energy Efficiency in the Residential Buildings Sector of Turkmenistan (EERB)", seeking to achieve the transformation of the buildings sector towards a more rational use of energy (and correspondingly curtailing greenhouse gas emissions). EERB focused on the renovation of the existing building stock and improve the design of more energy-efficient new buildings. Modernization efforts included the revision of building codes, improved designs (reduced energy loss in basic construction elements, such as roofs, cellars, and walls) and better practices (such as using automatic temperature regulators). By training professionals and demonstrating best practices (in a number of pilot buildings, the EERB Project has helped to improve energy efficiency in the residential buildings sector in Turkmenistan (see also Box 3 and Box 4 as well as a summary of achievements in Box 8). Through updating the regulatory framework, the project introduced revised building codes (SNT, from the Russian-language abbreviation[14]), namely a) SNT "Residential Buildings", SNT "Roofs and Roofing", SNT "Building Climatology" and SNT "Building Thermal Engineering". These were introduced during 2016-2017 and approved in 2020.

However, the Ministry of Construction and Architecture has not approved yet the corresponding "Instruction on the composition and procedures of project documentation for the construction of buildings". Also, the regulations on the rules and procedures for energy audits of residential buildings in Turkmenistan are still under consideration. These limitations shed doubt on how effectively the new energy-related building codes are implemented. The EERB's final evaluation report[15] hints at the replication of EERB's pilot and demonstration activities by means of a larger programme financed by climate financing (such as Green Climate Fund, GCF) or other sources but such a programme has not materialized. One lesson learned by EERB was that for any energy efficiency project to be successful, it has to reach beyond space heating (and heat losses through the building envelope) to address the efficiency of the cooling, lighting and other appliance as well as hot water provision because of their significant roles in residential energy consumption. In 2018, the Government's partnership with UNDP-GEF was expanded by a broader range of issues of sustainable urban development focusing on the related urban infrastructure (such as city public and private transport efficiencies, street lighting energy efficiency, electric grid efficiency and some hotel sector efficiency).

The Ministry of Construction and Architecture is implementing the *Programme of Socio-Economic Development of Turkmenistan for the 2019-2025 period.* This Programme outlines key strategic areas for sustainable development of the country in indicated period by investing among others in the construction of modern urban and rural developments with improved liveable conditions for residents and environmental considerations. The action plan of the Programme also envisages relevant measures to improve policy and regulatory framework to enable successful implementation of the strategic objectives of the programme[16]. Government investment programmes (such as under Decree 116) form a major source of TEESB's co-financing, as the programme goals align fully with the proposed project in the area of building modern, energy-efficient and smart buildings as well as drafting legislation and capacity-building.

Box 2 summarizes relevant other UNDP energy-related programmes in Turkmenistan. Other development partners, such as Asian Development Bank (ADB) and European Bank for Reconstruction and Development (EBRD) support or have supported several energy projects. As significant CO_2 emissions reductions can be achieved by reducing energy losses in the electricity

Corporation Programme

14 Building code of Turkmenistan (Строительные Нормы Туркменистана – in Russian)

15 *Terminal Evaluation* report (P. Janelidze, 2017)

16 Further to that programme, the President issued Decree No.1160 (March, 2019) decreed the construction of the new Ahal city agglomeration which should feature modern technologies with smart houses, smart buildings and other modern efficient management tools to showcase the achievements of Turkmenistan in line with the global technological developments.

and gas networks and by tackling the venting of methane in fossil fuel production, these projects have focussed on supply-side (natural gas, renewable energy) rather than demand-side efficiency (such as building efficiency and energy use).

1.3 Relevance to national priorities

Institutional setup

The Minister of the Ministry of Agriculture and Environmental Protection (MAEP) is the GEF political focal point, while the Head of Department of International Relations and Planning of MAEP is the GEF operational and UNFCCC focal point. The state remains a dominant player in the electricity market, in which generation, distribution, and transmission services are controlled by the utility Turkmenenergo. Natural gas markets are dominated by Turkmengaz, which acts as the country's primary developer, supplier, and seller of natural gas. Key institutions often play multiple roles in the housing and energy sector. Several key agencies influence residential construction and energy policy, and at the same time design and manage housing for their employees. The Ministry of Construction oversees construction targets, handles building codes and enforcement (through Glavgosexpertiz), but it also commissions, designs, and manages its own housing stock. Turkmengaz also commissions, builds, and manages housing for its employees through several subsidiaries, while its subsidiary Nebitgazkhyzmat is in charge of providing energy to new buildings that are constructed; another subsidiary, Neftegazstroy, serves as a contractor to Turkmengaz and is responsible for constructing employee housing and office buildings

Box 2 Policies and strategies related to energy and electricity

Policy/planning document	Relevance
National Strategy of Socio-Economic Development of Turkmenistan to the year 2030	The National Strategy sets targets for bigger average living space by increasing investment in residential construction (in many cases moving families from single-family dwellings into multi-unit apartment buildings
Law on Electricity	The Law provides an overarching framework for the regulation of the country's electricity generation, appointing the Cabinet of Ministers and the Ministry of Energy as the electricity sector's two main regulators. Moreover, financial incentives for energy efficiency projects are introduced, and accelerating the deployment of renewable energy has been set as an objective
Law on Licensing (2019) Law on Subsoil and the Law on Hydrocarbon Resources (2020)	The Law determines the process for obtaining licenses across all sectors of the economy, including in the energy sector. The power and fossil fuel sectors are dominated by the state-owned utilities Turkmenenergy, Turkmengas and Turkmenoil.
Law on Public-Private Partnerships (2021)	The Law on Public–Private Partnership regulates the process of preparing and implementing public-private partnership projects. Turkmenistan has two separate laws on investment, both of which establish the main rights and duties of investors (Law on Investment Activities in Turkmenistan (1992) and the Law on Foreign Investments (2008)
National Climate Change Strategy of Turkmenistan	The Strategy (adopted in June 2012) considers energy efficiency and savings and the increased use of alternative energy sources as the main priorities of the policy, oriented towards the reduction of GHG emissions. According to the Strategy, priorities for developing the housing and municipal services sector include a) improving the performance efficiency of municipal heating supply systems, b) improving the regulatory framework for construction standards and rules towards ensuring energy efficiency and heating supply security of buildings, and c) promoting public awareness raising and motivation activities
National Strategy on Development of Renewable Energy for the period up to 2030 Law on Renewable Energy (2021)	The National Strategy on Renewable Energy was issued in 2021. The Government will develop several legal-regulatory documents that complement and enable the implementation of the Strategy. UNDP jointly with the Ministry of Energy, and the State Energy Institute of Turkmenistan has worked on the development of the new Laws of Turkmenistan "On Renewable Energy Sources" (adopted by the Parliament of Turkmenistan on March 13, 2021) and "On Energy Efficiency and Energy Saving" (under consideration of the Parliament of Turkmenistan). The Law on Renewable Energy (2021) determines legal, organizational, economic and social bases of activities in the field of renewable energy resources and governs the arising relations connected with the use of renewable energy resources. The Law's stipulations include major incentives for renewable energy projects (including easier land leases, and guaranteed purchase of electricity generated from renewable sources).

Turkmenistan's Third National Communication to UNFCCC (2016) stresses that "Implementation of a large-scale urban development program will be continued in the construction sphere. Modern villages will be built in all regions of the country; populated areas will be equipped with modern conveniences and become green; social and cultural objects will be built, as well as major infrastructure facilities of fuel and energy and transport sectors, and others (pg. 89). The importance of energy efficiency is stressed:

- "Throughout the whole period under review, increase in production of high quality, competitive products will be based on introduction of modern energy-saving and environmentally friendly technologies. In this regard, special attention will be paid by the state to energy conservation policy……The introduction of energy-saving, high technology reduces specific energy consumption, increases labour productivity, and provides price and non-price competitiveness of goods and services. For integration into this policy of energy saving incentive mechanisms there will be required a phased reform of the growth in selling prices and energy tariffs"
- Page 94: "Construction of energy efficient buildings using energy efficient materials and technologies, improving of thermal insulation and sealing of buildings, using modern materials and constructions of walls, roofs, doors and windows, as well as high-efficiency heating, ventilation, air conditioning and water heating systems; Installation of electricity, heat, gas and water meters and organization of systematic monitoring, inspection of buildings for heat leak by thermal imagers, and others"

1.4 Barriers to energy efficiency and gaps in sustainable building construction

Development problems and solution:

The market for residential buildings has been growing rapidly at about 40% every 6-7 years and this trend will continue. Whereas in the year 2000, the living space per person in Turkmenistan averaged only 7.8 m^2, in 2007 it was 19.9 m^2, in 2020 the figure exceeded 21.1 m^2 and still increasing in new, more luxurious, apartment buildings (see Annex G). The energy consumption in the residential and service sector is likely to more than double by 2030 with a corresponding increase in greenhouse gas emissions.[17]

The long-term solution for a sustainable reduction of GHGs from the buildings sector is to reduce and potentially stop the construction of any new residential and public buildings with significant GHG footprints[18]. Multiple types of savings and economies of scale can be obtained when modern building technologies are utilized in the design and construction to reduce energy losses (see Box 4). The greenhouse gas emitted from the remaining energy consumption in the building for heating, cooling and ventilation) can be compensated for by using renewable energy, e.g., solar photovoltaics (PV) and solar water heating (SWH) to get a 'near-zero emissions' building (NZEB, see Box 5; for NZEB approaches in the European Union, see Box 6).

The EERB project can be regarded as a first step in the right direction by the first demonstration of energy-efficiency options in building construction and design, formulation of energy-relevant building codes and associated capacity building.

[17] *CAREC Energy Outlook 2030* (ADB, 2021). Final energy demand in residential and service sector will increase from the current 7.5 Mtoe (2020) to about 18.2-20.0 Mtoe by 2030.

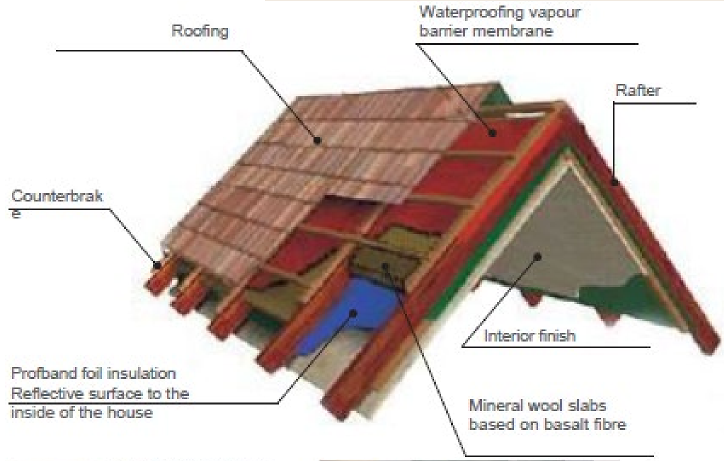
[18] Apart from energy consumption for heating, cooling and ventilation, about a quarter of total electricity consumption in the residential and services sector is for major household and electric appliances (including electrical bulbs, air conditioners, washing machines, office equipment) Although regarding electric appliances there is also a significant need for energy efficiency improvements, these are not included as subject of TEESB which focusses on energy losses through the building fabric.

Box 3 Energy-efficient building construction and design

The revision of the building codes of Turkmenistan Norms for Construction (TNC) on "Roofs and Roofing", TNC "Residential Buildings", TNC "Building Heat Engineering" and SNT "Building Climatology". These provide rules and guidelines for the rules design, construction and operation of buildings and structures.

Roofs and roofing

The roof of a building or the roof is the upper structure of the building, which serves as protection against precipitation, rain and melt water. Another main function of the roof is thermal insulation (preservation of heat and protection against overheating). Energy consumption can be reduced by improved thermal insulation of roofs and roofs, and consequently reduced heat losses of the building in winter and heat gains in summer (see picture on the rights, above)

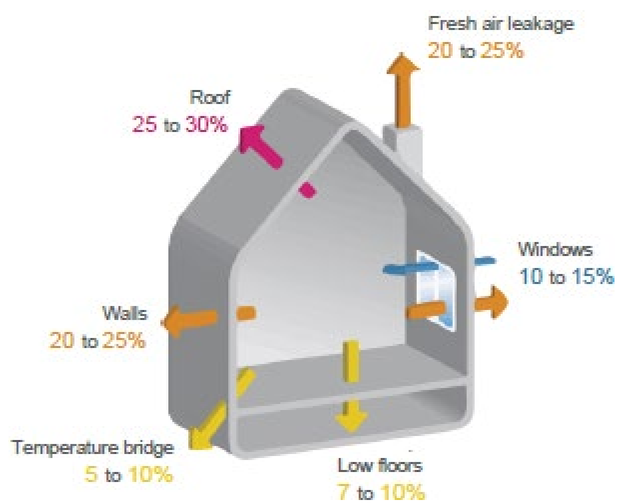


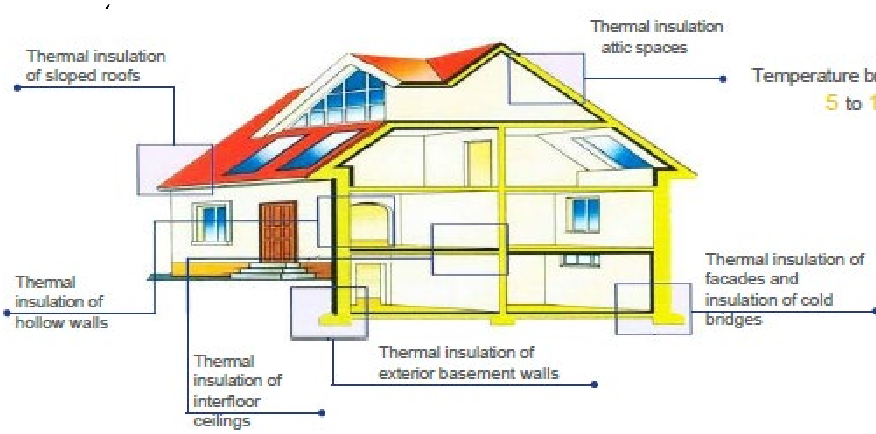
Vestibules in multi-storey buildings

The building code requires the provision of vestibules at all exterior entrances to residential buildings and underground garages (see figure on the right below). It is estimated that this can save up to 4% of energy for heating and cooling. The norms also recommend the use of energy-efficient lighting fixtures with compact fluorescent or LED lamps of 9-11 W in combination with motion sensors for the lighting of stairwells of elevator halls and floor corridors.

Building external envelopes

A building has an external envelope that demarks the volume of the building, while individual rooms or apartments are enclosed by internal envelopes. Examples of exterior envelopes are exterior walls, windows, exterior doors, and roof coverings. Internal building envelopes (load-bearing or non-bearing) separate building volumes with different air temperatures or noise levels. Examples of internal building envelopes are walls and partitions, floors, basement, and attic ceilings. In winter the heat loss in the residential building occurs through the building envelope and through the ventilation system. The same elements are used for heat input to the building in





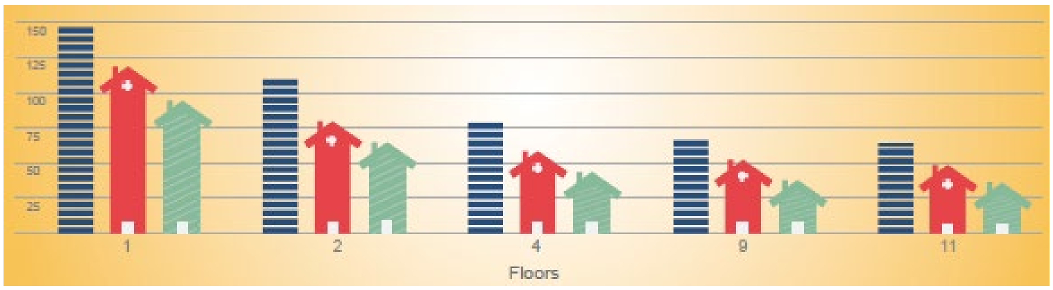
All heat losses (see figure above) and heat gains are compensated by additional energy consumption for heating and ventilation in winter or cooling and ventilation in summer. The more insulated the building envelope is (see figure on the left), the better it protects the interior of the building from the weather.

Source: Revised Building Codes of Turkmenistan “Roofs and Roofing", "Residential Buildings", Construction Climatology", "Construction Thermotechnics", "Construction Thermotechnics” UNDP/GEF EERB project

Box 4 Energy consumption savings in energy-efficient buildings

The norm on 'building heat engineering' foresees the element-by-element of a number of requirements, regarding reduced heat transfer resistance, specific thermal protection characteristics, .air permeability, specific annual energy consumption for heating, cooling and ventilation, protection against moisture, heat absorption of flooring surface and other requirements. The figure on the right shows the impact of the implementation of the norm on buildings on the thermal resistance of the envelop structures.

The amount of heat energy saved (for heating and ventilation) significantly depends on the presence of automatic control in the building heating system. This all translates into norms for specific energy consumption (in kWh per surface area) according to the size of a multi-storey building, as shown in the figure on the left.



Before introduction of construction norms (TNC)
New norms, without automated heat control
New norms, with automated control (AHC) (in kWh/m²)

It has been estimated that the application of the Turkmenistan Norms for Construction can lead to substantial energy savings in a building in comparison with buildings that do not comply:

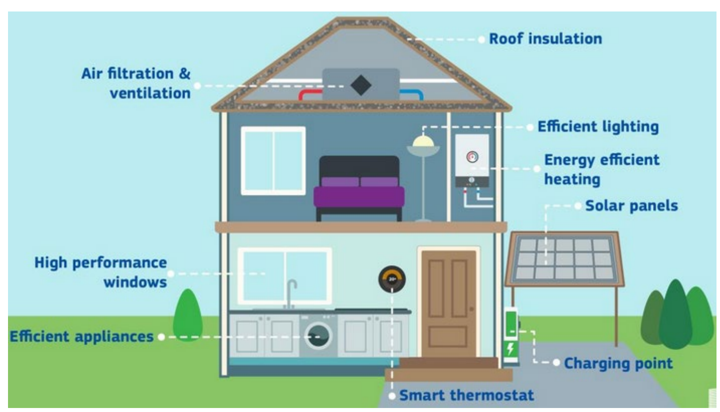
- Heat energy for heating and ventilation in residential buildings of social standard with automatic regulation of the heating system 42-47%, without regulation 26-28% (thus the effect of AHC is about 16-20%);
- Electric energy for cooling and ventilation by residential buildings 14-17%

The EERB project carried out monitoring of three renovated buildings (5-9 floors with 40-45 units with savings after reconstruction of 31.1-32.0% in heat and 55.7-64.9% in electricity and 71.7-81.5% in natural gas. Similarly, the new buildings (9-12 floors with 54-112 units) with heat savings of 28.8-31.5 and electricity savings of 50.2-64.7%.

Nearly-zero emissions buildings (NZEB)

Nearly zero-emission building (NZEB) means a building that has a very high energy performance, while the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby, such as solar photovoltaic, solar water heaters or geothermal energy.

Given the Paris Agreement's push to move towards a net-zero carbon emissions world by 2050, it is essential that Turkmenistan adopts an enforceable NZEB standards for all new buildings. This means the building codes need to be further revised to achieve reductions of at least 50% relative to the standards currently in place while employing on-site renewable energy as well as the installation of an Energy Management Information System (EMIS) in large (public) buildings) that have high energy consumption rates. For example, the European Union Energy Performance of Buildings Directive (EPBD) introduced the NZEB standard as a mandatory requirement for all new buildings in EU countries starting from January 2021 (while for all new public buildings that standard came into force earlier).



Source: Infographic "Improving energy efficiency in the residential building sector of Turkmenistan", EERB project; Revised Building Codes of Turkmenistan "Roofs and Roofing", "Residential Buildings", Construction Climatology", "Construction Thermotechnics", "Construction Thermotechnics" UNDP/GEF EERB project. EU: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en#zero-emission-buildings

Box 5 Definitions of net zero and nearly zero

There are no official definitions, but some common terms are:

- *Net-zero carbon buildings* reduce energy demand as close to zero as possible, with all remaining energy needs satisfied by renewable energy sources, focusing on operational emissions.
- *Net-zero whole-life carbon buildings* minimise on-site embodied carbon and compensate for all residual emissions in the supply chain in addition to the measures targeted by net zero carbon buildings.
- *Nearly-zero carbon building*s are where on-site actions to reduce energy demand and install on-site renewable energy systems have been maximised, but other factors – such as limits to city powers over the electricity grid – mean insufficient offsite renewable energy is available to meet 100% of a building's needs. This typically excludes embodied carbon.
- *Net-zero energy buildings* produce as much renewable energy on-site as the building consumes on an annual basis and are usually highly energy efficient. Unlike net zero carbon buildings, these buildings have not necessarily switched from fossil fuels to electrified equipment and appliances, and this approach typically excludes embodied carbon.
- *Nearly-zero energy buildings* have a very high energy performance, while the low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

<u>Barriers and gaps to the design and construction of high-efficiency buildings</u> (in the residential and services sector)

To achieve a wider replication of the results of the EESB project and move towards NZE construction, several important barriers and gaps remain:

1. Low energy prices and electricity tariffs resulting in excessive payback periods

A long period of provision of free electricity and natural gas for a large share of the population (and low tariffs for those who pay) has led to low awareness of efficiency in energy (and water use). From 1993 to 2017-2019, citizens even received government-provided electricity, water and natural gas almost free of charge. The idea was that by providing subsidized utility services, the population would enjoy a high standard of living. Recently, the government has started implementing gradual tariff reforms to transition and adopt market measures in the management of the national economy and gradually phasing out subsidies for natural gas, electricity, water and table salt to citizens. The Decree prescribing the abolition of the free supply of electricity, gas, potable water, and table salt to citizens was signed in January 2019. However, there is no clear action plan with specific regulations to achieve the full transition to a zero-subsidy regime for fossil fuels.

Thus, there remains the obvious disincentive for end-users to make efforts to reduce energy consumption, due to the very low tariff for heat and electricity in Turkmenistan. In the longer run, there is a clear incentive for the government itself to reduce end-use consumption of natural gas: exports of natural gas provide valuable revenues to the state budget, while internal consumption is financed mostly by the government. Therefore, any natural gas saved through energy efficiency can be exported; the financial gain for the government is the difference between international market prices and having no or having negative revenue (counting the cost of fuel subvention).

2. Energy-relevant building codes are not in line with nearly-zero requirements

Given the Paris Agreement's push to move towards a net-zero carbon emissions world by 2050, Turkmenistan must also move towards enforceable NZEB standards for all new construction. The latest set of energy-efficiency building codes (approved in 2020 and formulated with support from the EERB project; see Box 8) is already in need of being updated for new buildings if the aim is 'nearly-zero energy'. This means that the 2020 building codes need to be further revised to achieve further energy demand reductions of about 50% relative to the energy performance implicated in the standards currently in place (by making the building envelope energy-efficient) to meet the residual demand by using renewable energy sources (such as rooftop solar panels and solar water heaters) as much as possible.

Over the past two decades, the Government of Turkmenistan has ratcheted up residential construction. Significant funds are allocated to flagship projects, such as the construction of Arkadag (in Ahal *velayat*) and the Ashgabat City megaproject, situated north of the capital. In such interventions, the keen to show its achievements by building its infrastructure according to the latest technology requirements. However, for the majority of non-high-profile residential and public buildings, the energy performance situation will be quite different.

3. Lack of institutional capacity for the update, verification and enforcement of energy-efficiency building codes

Most contemporary, multi-unit, high-rise apartment buildings have been built in the past two decades, that is, based on 1998 building codes (and older buildings according to Soviet-era norms and practices). The latest energy-relevant construction norms were updated with support of the UNDP/GEF EERB project and introduced in 2020 (SNT "Residential Buildings", SNT "Roofs and Roofing", SNT "Building Climatology" and SNT "Building Thermal Engineering; see Annex G). However, the Ministry of Construction has not approved yet the corresponding "Instruction on the composition and procedures of project documentation for the construction of buildings". However, the regulations on the rules and procedures for energy audits of residential buildings in Turkmenistan are still under consideration. Thus, while the implementation of TNC standards was enforced through a design review and site checks, no actual auditing is required to determine the energy performance of buildings. These limitations shed doubt on how effectively the new energy-related building codes are implemented.

While current regulation calls for building codes to be updated every five years or so, what is lacking is clear legislation (with an action for its implementation) for minimum energy performance codes in particular and for promoting rational use of energy in buildings in general and necessary institutional setup for monitoring, verification and enforcement (MVE). Such plans have been proposed in the past, but in practice face a difficult path to approval by the Cabinet of Ministers of Turkmenistan, in particular when budget commitments are implicated.

While the various government agencies (at the national and local level) have the financial resources to invest in highly energy-efficient, expensive, buildings, they often lack the specific expertise and knowledge to effectively pursue the idea of taking into account high-efficiency or integrating renewable energy in building design and construction. Many staff of the Ministry of Construction (and other government entities) have been trained to implement obsolete construction standards before the latest set of norms and standards (promoted in the before-mentioned EESB project) were approved in 2020. These standards did take account of the energy efficiency requirements (in terms of the maximum specific heat consumption per m^2 per degree-day) but they did not consider the energy performance of buildings per se and thus there were no incentives to construct buildings that would exceed those performance requirements. The Government is constrained in its technical capacity to design legislation to enact implementation, verification and enforcement systems to implement the current building codes and to update according to the latest international development, such as norms for nearly-zero buildings.

4. *NZE technologies and measures have not been demonstrated in Turkmenistan, while related knowledge and technical skills need to be improved*

Currently, no building is constructed having NZEB standards in mind and applications of renewable energy (e.g., solar PV or solar thermal) are normally not integrated with building designs. Architects, engineers, and policy-makers have insufficient knowledge and capacities to identify techniques that correspond with requirements on low-carbon or net-zero carbon goals (NZEB). As a result, an innovative market for these types of buildings will not develop with local architects and engineers not up to date in skills and knowledge.

5. *Regulatory and investment barriers to sustainable energy investment*

The primary barriers to doing business in Turkmenistan are the lack of policies and information. Additionally, power plants are ageing, but there is no official power sector modernization plan in place. In 2022, the Ministry of Energy announced a tender for materials for solar panels; in the next few years, more tenders or installation auctions are likely to be held for utility-scale power generation. Renewable energy generation in small and medium-sized installations in remote and sparsely populated areas is planned for the short term. Additional action is required to improve Turkmenistan's appeal to investors, including the establishment of a clear power tariff structure (and higher transparency in the tariff-setting process), shortening the lengthy administrative processes, and opening the electricity generation market. The establishment of special incentive schemes for renewable energy projects, such as feed-in tariffs or a capacity auction on a least-cost basis, would potentially lead to a higher investment inflow. Similarly, the introduction of net metering would help the dissemination of rooftop PV on buildings.

However, in practice, there is little incentive for private or foreign companies to enter the country's energy sector, as it is opaque, and completely controlled by the state with no supportive policy framework in place[19], despite recently introduced legislation of investment and public-private partnerships that establish the rights and duties of investors.

In general, private sector participation in energy generation remains hindered by bureaucratic obstacles. For example, the process of registering a business requires a challenging set of formalities. The business climate suffers from the large role

Box 6 NZEB requirements in the European Union

Since the beginning of 2021, all new buildings constructed within the EU must be nearly zero energy buildings (nZEBs), according to Article 9 of the EU Energy Performance of Buildings Directive 2010/31/EU (EPBD). The Directive further stipulates that all new buildings occupied and owned by public authorities constructed after 31 December 2018 must be nZEBs. Clause 3 of EPBD Article 9 requires Member States to define their nZEB requirements in their national plans, including a numerical indicator of primary energy use expressed in kWh/m2 per year. These may be varied for different building typologies within a country based on the climatic zone, heating system, building geometry and other factors. In addition to climatic variations within a country, the European Commission has considered EU-wide climatic zones. In its 2016 nZEB Recommendations, the European Commission published its benchmark thresholds for primary energy across the EU, differentiated according to four main climatic zones: Mediterranean, Oceanic, Continental, and Nordic.

	Net primary energy ($kWh/m^2/yr$)	*Energy supplied from renewable energy (RE) (kWh/m2/yr)*	*Primary energy threshold (incl. RE) (kWh/m2/yr)*	*Mid-point share of RE in primary energy (kWh/m2/yr)*
Single-family house				
- Mediterranean	0-15	50	50-65	87%
- Oceanic	15-30	35	50-65	61%
- Continental	20-40	30	50-70	50%
- Nordic	40-65	35	65-90	32%
Offices				
- Mediterranean	20-30	60	80-90	71%
- Oceanic	40-55	45	85-100	49%
- Continental	40-55	45	85-100	49%
- Nordic	55-70	30	85-100	32%

A number of Member States do not specify $kWh/m^2/yr$ value ranges for energy performance for new buildings as part of their nZEB requirements (performance codes). Instead, they are based on minimum performance levels or achievable performance ranges calculated in comparison to reference buildings and considering building typology, U-values, geometry, climatic region, and a range of other factors (prescriptive codes).

Source: *Nearly Zero: A Review of EU Member State Implementation of New Build Requirements,* BPIE (2021)

the state plays in the distribution of resources. Access to foreign exchange is highly restricted and private capital is to a large extent held in the parallel economy.

[19] Source: https://global-climatescope.org/markets/tm/

2. NEARLY-ZERO ENERGY INTERVENTIONS IN BUILDINGS

2.1 Results of the EERB project with energy-related construction norms (SNT)

The GEF-supported UNDP-implemented project "Improving Energy Efficiency in the Residential Building Sector of Turkmenistan" (EERB Project) aims to reduce greenhouse gases (GHG) emissions by improving energy management and reducing energy consumption in the residential building sector of Turkmenistan. The EERB Project consisted of four components: (i) Energy efficient building codes and supporting capacity strengthening; (ii) Demand-Side Management partnership with Turkmengaz (the local executing agency of the project); (iii) Improved design measures for major residential consumers; and (iv) Replication through training and support for policies that encourage energy efficiency.

Overall, this EERB Project has had a sustainable effect on the improvement of energy efficiency in the residential buildings sector in Turkmenistan. Through updating the regulatory framework, the project introduced revised building codes (SNT, from the Russian-language[20] abbreviation), namely a) SNT "Residential Buildings", SNT "Roofs and Roofing", SNT "Building Climatology" and SNT "Building Thermal Engineering. These were approved during 2015-2017. Through the implementation of pilots, the project demonstrated the best practices of design, energy performance and energy management in new/renovated residential buildings; and through the capacity building activities and outreach program created a local capacity and capabilities of local dedicated institutions and professionals for replication and scaling up of these activities in a sustainable way. A summary of the main results is given in Box 8 While the project has helped to define the new building codes, unfortunately, the Ministry of Construction has not approved yet the corresponding "Instruction on the composition and procedures of project documentation for the construction of buildings". This sheds doubt on how effectively the new energy-related building codes are implemented.

Several audits were carried out as part of the EERB Project, measuring heat and electricity consumption in new residential building complexes and in newly constructed buildings. These were summarised in a project infographics publication (see Box 7 for a summary). The savings (in MWh and kWh/m^2) mentioned for different types of residential buildings have been used to compute the typical energy consumption for heating, ventilation and cooling in a typical 9-storey and a 12-storey apartment building.

Based on EERB project reporting on thermal transmittance and other characteristics of the building envelope in combination with monthly temperature averages, an attempt has been made to calculate the energy losses for a residential building, considered typical as TEESB pilot with 30 apartments on 4 floors) constructed at the current energy building norms and before their introduction. The results (energy consumption of 633 MWh/yr; see Box 10) roughly correspond with the energy consumption of a nine-floor residential apartment building measured in the EERB-supported audits (about 615 MWh per year)[21].

Box 7 Energy demand for heating, cooling and ventilation in new buildings (before introduction of current SNT, building codes)

	Energy consumption			*Energy per floorspace*
	Before SNT norms	*At current SNT norms*		*(kWh per m^2)*
9-floor (54 apartments)		4,968	m^2	
Space per appartment		92	m^2	
Energy for heating	496	340	MWh/yr	68.4
Energy for cooling	118	75	MW/yr	15.2
12-floor (luxury 72 units)		22,464	m^2	
Space per appartment		312	m^2	
Energy for heating	1,924	1,307	MWh/yr	58.2
Energy for cooling	665	332	MWh/yr	14.8

Data calculated based on I*mprovement, energy efficiency in the residential sector Turkmenistan's construction, Results of energy audits of apartment buildings in Turkmenistan* (UNDP 2017a), *Key Achievements of the UNDP/GEF Project* (project infographics, UNDP, 2017b)

20 Строительные Нормы Туркменистана (SNT) – Construction Norms of Turkmenistan

21 The amount does not include the electricity use of

Box 8 Key achievements of the UNDP/GEF EERB project

Product	Status
- Building code "Residential Buildings" - Building code "Roofs and Roofing" - Building code "Building Climatology" - Building code "Building Thermal Engineering" - Guidance manuals for the above-mentioned building codes and summary report	- Developed and adopted - Developed
Guidance and instructions: - Planning and implementation of energy management for existing residential buildings in Turkmenistan - Methodology for energy audit of residential buildings and provisions on rules and process for energy audit in residential buildings of Turkmenistan - Development, commissioning and operation of the automated heat control/regulation - Software package 'energy passports in buildings'6 - Catalog of materials and assemblies for reducing heat losses in the design of building envelope elements; Assessment of EE benefits - Manual on improving the energy efficiency of residential buildings	Developed
- Building code "Instruction on the composition, procedure for the development, approval and adoption of project documentation for the construction of enterprises, buildings and structures"	In process of adoption
- Building code "Heating, ventilation and air conditioning"	Changes on EE integrated
- Energy audits (with reports and summary report) in 22 pilot residential buildings in 9 cities of Turkmenistan; 6 pilot buildings (3 new for construction, 3 for renovation) in Ashgabat (9-storey 54-apartment house; elite 12-storey 114-apartment residential building; elite 12-storey 66-apartment residential building; 3 pilot reconstructed residential houses . Installation of energy management system and monitoring of energy consumption in 5 pilot buildings in the residential area of Koshi micro-district.	Developed
- National Action Plan for Rational Use of Energy in the Residential Sector - Scenarios for EE renovation of the residential building sector - Financial assessment and investment plan for the renovation of the residential sector	- Under consideration - Developed - Developed
- Revised Curricular program for students of TSIAC - Lecture material and practical work for the section "Energy Saving" - Laboratory works for the section "Energy saving" - Energy Saving Laboratory - Competition for students of TSIAC - Management of the preparation of the diploma theses for students of the TSIAC	- Adopted - Developed - Developed - Equipped - Developed, -Implemented

Compiled from *Terminal Evaluation, Improving Energy Efficiency in the Residential Building Sector of Turkmenistan (EERB),* by P. Janelidze (2017)

In Turkmenistan, building code requirements concern newly constructed buildings. In terms of minimum energy performance requirements, there are none, neither for newbuild nor renovated buildings. However, the current building codes contain prescriptive/element-based criteria for thermal insulation. The overall thermal coefficient of a building (referred to as a global heat transfer coefficient, G [in W/m^3K]) of the heated volume will vary as a function of the number of levels of the building and external area per volume ratio (A/V).

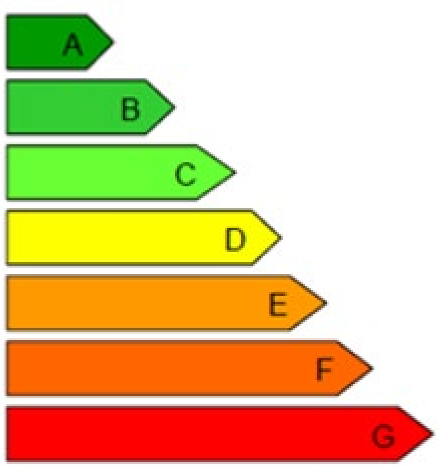
electric appliances by the apartment dwellers (but does include as part of 'free heat' the heat generated as a consequence of using these appliances).

Box 9 Building envelope, thermal resistance values and energy passports

Buildings and facilities	Heating Degree-days [°C · day]	Building envelope thermal resistance minimum values R-value [m². K/ W]				
		Wall	Roofs and ceilings above corridors	Attic ceilings, structures above cold basement and underground	Windows and balcony doors	Vestibule and lobby
Residential buildings, hospitals, schools, dormitories	2000	2,1	3,2	2,8	0,3	0,3
	4000	2,8	4,2	3,7	0,45	0,35
	6000	3,5	5,2	4,6	0,6	0,4
	8000	4,2	6,2	5,5	0,7	0,45
	10000	4,9	7,2	6,4	0,75	0,5
	12000	5,6	8,2	7,3	0,8	0,55
Other buildings, office and residential buildings, except for premises with higher indoor humidity	2000	1,6	2,4	2,0	0,3	0,3
	4000	2,4	3,2	2,7	0,4	0,35
	6000	3,0	4,0	3,4	0,5	0,4
	8000	3,6	4,8	4,1	0,6	0,45
	10000	4,2	5,6	4,8	0,7	0,5
	12000	4,8	6,4	5,5	0,8	0,55
Buildings operated in dry and normal conditions	2000	1,4	2,0	1,4	0,25	0,2
	4000	1,8	2,5	1,8	0,3	0,25
	6000	2,2	3,0	2,2	0,35	0,3
	8000	2,6	3,5	2,6	0,4	0,35
	10000	3,0	4,0	3,0	0,45	0,4
	12000	3,4	4,5	3,4	0,5	0,45

Source: CHT 2.01.03-98 Строительная теплотехника – Turkmen Code on Building Thermal Engineering.
Note: U-value = 1 / R-value

Examples of energy passport of buildings



Energy performance (deviation actual heat resistance from indicator value). R_N: new building; R_E: existing building	
Example 1	Example 2
A++ EP < 0.4 R A+ 0.4 R < EP < 0.5 R A 0.5 R < EP < 0.6 R	A: EP < 0.5 R_N
B+ 0.6 R < EP < 0.7 R B 0.7 R < EP < 0.85 R	B: 0.5 R_N < EP < R_N
C+ 0.85 R < EP < 0.95 R C 0.95 R < EP < 1.05 R C- 1.05 R < EP < 1.15 R	C: R_N < EP < 0.5 (R_N+R_E)
D 1.15 R < EP < 1.5 R (existing buildings)	D: 0.5 (R_N+R_E) < EP < R_E
E EP > 1.5 R (existing buildings)	E: R_E < EP < 1.25 R_E
F	F: 1.25 R_E < EP < R_E
G	G: 1.5 R_E < EP

Box 10 Calculation of energy flows (heating, cooling, ventilation) in a 9-floor residential building

Before introduction of current SNTs					At current SNT (EESB project)		At NZE practice (TEESB project)	
Energy transmittance values					*Current values*		*NZEB values*	
	Area (m2)	*U value W/(m2.K)*	*Contribution W/K*		*U-value W/(m2.K)*	*Contribution W/K*	*U-value in NZEB*	*Contribution W/K*
Wall	2055.6	1.0	2055.6	U*area (wall w/o window)	0.6	1233.3	0.2	411.1
Roof	754.3	0.7	528.0	U*area (roof)	0.33	248.9	0.15	113.1
Basement	754.3	1.1	829.7	U*area (basement)	0.67	505.4	0.4	301.7
Window	614.0	2.7	1657.8	U*area (window)	1.7	1043.8	1	614.0
- % of wall	23%			% of wall area				
Envelope	4178.2	*1.214*	5071.1	a (=sum of above)	*0.73*	3031.4	*0.34*	1440.0
Lack of vestibule			425	b; own estimate				
Energy losses/gains								
Degree.hours [K.hr]			2801	q (see footnote)		2801		2801
Energy flow- convection [MWh/yr]			369.5	$d=c*(a+b)*24/1.10^6$		203.8		96.8
Energy flow - ventilation			144.5	e=n*f*c*V*24/1.106		144.5		144.5
ACH (n)	0.35			n: air exchange per hr			0.35	
air heat flow	0.34			f: 1204*1002/3600				
Heat recovery ventilation			0			0	60%	57.8
Energy flow (MWh/yr)		Total	514.1	h=d+e	Total	348.4		154.6
Heating and cooling needs								
Heating		Heat	415.5	i, see footnote		281.6		125.0
		Free heet	87.1	j, see footnote		87.1		87.1
		Hot water need	123	k, see footnote		123		123
Heating need	18%	w/o AHC	**510.9**	m=(i-j)*(1+20%)+k	w/o AHC, meters	**352.9**	with AHC	**161.3**
Cooling		Heat gain	98.5	c, see footnote		66.8		29.6
		Free heat	33.1	o, see footnote		33.1		33.1
Cooling need	3%	w/o AHC	**136**	p=(n+o)*(1+3%)	w/o AHC, meters	**102.9**	with AHC	**62.8**
Total			***646.5***	MWh/yr		***455.8***		***224.0***
Energy consumption								
Gas consumption						392		179
Efficiency burning, boilerr					90%	1411	90%	645
						51659		23609
						77.6		35.5
Electricity consumption								
IPLV, chiller					3.8	27.1	4.4	14.3
						18.8		9.9
					TOTAL emissions	96.4		45.4

The tables provide an example of how gas consumption (for heating) and electricity (for cooling) when building according to current norms (approved in 2020) and to more stringent net-zero energy (NZE) norms in comparison without the situation before the EESB project.

Notes:

- degree hours are taken from item q in Box 23
- free heat (human body heat, heat generated by electric appliances) estimated assuming 6.66 kWh per apartment per day calculated over heating days per year (giving j) and cooling days (giving c); see Box 24
- hot water needs provided with boiler system, consumption assumed at 120 litres per apartment per day (heating difference 40 K), c_{water}= 4.186 KJ/(kg.K)

Data are calculated based on information provided in UNDP EERB reports (see UNDP 2017a and 2017b, as referenced in Box 19); information on internet on ventilation values and heat losses; *Implementing Nearly-Zero Energy Buildings, Romania, Poland* (Buildings Performance Institute, BPIE; 2012)

2.2 Comparison of NZEB options with reference buildings

To analyse the impact of the introduction of 'nearly zero energy building options' (NZEB) two reference buildings are considered in this Annex (and form the basis for the baseline greenhouse gas emission reductions of the proposed TEESB Project.

The first reference building is a 5-floor residential building with 30 apartments and a total floor area of 7,020 m^2 (of which 4,588 m^2 of apartment space on 4 floors). The energy losses/gains through the building envelope and ventilation are calculated similarly to the 9-floor apartment building example, discussed in the preceding paragraph. The roof is flat, and it is assumed the floors are heated to 20.5ºC in winter. The heating is assumed to be with an air heat pump system (see Box 13) as an alternative to the assumed base case of using a central system comprised of a chiller (powered by electricity) for cooling and a boiler (powered by natural gas) for heating. Cooling is at a set point of 25ºC. The domestic hot water system is linked to the heating system[22]. The second reference is an office building with seven floors and a total floor area of 7,680 m^2 with its boiler system (of which 5,776 m^2 of office space). None of the reference buildings applies renewable energy options. In both reference cases, no automatic heat control system or advanced energy management systems are applied (that can tune to heat supply in real time to the actual outside temperature) and the apartments or office space s do not have individual heat metering in the central boiler-chiller system[23].

It is assumed that the reference buildings are constructed according to the current SNTs (2020 building construction norms). Building requirements (including the minimum thermal performance of building components) are controlled at the stage of construction authorisation (building permit). In principle, the requirements are respected in the design documentation, otherwise, the construction project does not pass the authorisation process. However, in practice, the execution of the work may not be undertaken according to the design as the necessary "Instruction on the composition and procedures of project documentation for the construction of buildings" has not been officially approved yet. Thus, the result may depend on the budget made available by the investor. In addition, the poor execution of details/joints (thermal bridges) can lead to a reduction of the global thermal resistance of the building envelope.

For the NZEB case, a number of energy-saving improvements are considered:

- Construction of an improved building envelope (with a higher U value for its walls, windows, attic and basement)
- Heat recovery module added to the building's (mechanical) ventilation system
- Central system using a ground source heat pump in case of the office building with automated heat control and advanced energy management information system (EMIS)
- Apartment-based air heat pumps in the case of the apartment building with automated heat control (AHC)

Box 11 Monthly average temperatures, Ashgabat/Ahal

			Set point (ºC)	
			Heating	**Cooling**
Average temperature (ºC)			**20.5**	**25.0**
Ashgabat / Ahal area			Temp. difference (K)	
Jan	2.7	31	17.76	
Feb	4.5	28	16.03	
March	10.4	31	10.1	
Apr	17.2	30	3.26	
May	23.3	31		
June	30.0	30		5
July	32.0	31		7
August	30.0	31		5
Sept	25.5	30		0.5
Oct	18.5	31	2	
Nov	11.0	30	9.5	
Dec	4.1	31	16.36	
			K*days	
		Total [K.day]	2801	q
		- heat loss	2264	r
		- heat gain	537	s

Source: based on data provided in worldweatheronline.com and *Revised Building Codes* (UNDP, EERB project, 2017)

22 It is assumed here that each apartment has an individual system for heating and DHW (domestic hot water) production. Alternatively, there can be heat pump per floor and/or for heating and DHW separately (see Box 25)

23 In the base case, a gas boiler usually provides heat for a small group of apartment buildings (as a micro district heating system)

- Addition of grey water recycling and re-use system for the office building

In these cases, heating systems provide heating in the winter period and hot water while cooling is needed in the hot summer months. Building space is also heated by 'free heat' gains from the occupant's bodies, lights and appliances as well as passive solar gains (solar radiation penetrating through the windows). Heating (and cooling) is needed to add to (or compensate) for the 'free heat' and energy flows through the building's envelope and keep the temperature in the building at acceptable values. Energy flows in and out through the building fabric (its walls, roof, floor and windows) as well through ventilation (moving the air through the building and eventually inside and outside).

Cutting the building envelope heat losses (in winter, or gains in summer) is using materials that give the wall, roof, floor or window a lower heat flow. This can be expressed by their *U-value (heat transmittance)*. The U value is the heat flow per surface area] divided by the temperature difference (outside minus inside temperature) into the units Watt per (Kelvin x square metre, W/(K.m^2). The lower the U-value, the better the insulation performance. In walls, roofs and floors **conduction** is the main mechanism of heat flow and this can be reduced by incorporating one or more of a range of insulating materials. The heat flow is determined by the characteristics of the building and insulation material (thermal conductivity, in [W/(m.K] and the thickness (in metres, [m]). The lower the conductivity and the higher the thickness, the better the insulation. The U-value of a wall or roof is determined by the characteristics of its composite elements (such as brick or concrete, plaster, mineral insulating wool or polystyrene foam, etc.). Windows were traditionally single-glazing with a high U-value of about 4.8). A double-glazed window (argon-filled) has a value of between 2.0 and 1.5, while triple-glazing can have 1.3-0.8 (depending on coating, thickness, and airtightness).

Box 12 Base date used in energy efficiency and renewable energy calculations

Natural gas	36.6 MJ/m3
- heating value	47.1 MJ/kg
- carbon content	55 kgCO2/GJ
Grid factor	0.63 tCO2/MWh
Efficiency power	
generation from gas	31.4%
T&D losses	10%
Lifetime EE and RE	20 yrs
Solar energy - Ashgabat	
Direct normal irradiation	1511 kWh/m2/yr
Global tilted radiation	1918.5 kWh/m2/yr
	4.05 sunhrs/day
Solar PV panel output	1479 kWh/kWp
Watts per area	0.221 kWp/m2
Cost of PV	1250 USD/kWp

Source: power sector data from solar data from project papers produced by the UNDP/GEF GURB project (Integrated Green Urban Development).
Heating values from www.engineeringtoolbox.com.
Prices of solar PV and SWH based on *Implementing nearly Zero-Energy Buildings* (nZEB) series (BIEE)
www.globalsolaratlas.info/map?s=38.02438,58.708989&m=site&c=37.99508,58.539619,11: solar data

Buildings also lose heat by **ventilation**, i.e., the passage of air through them. This normally means the controllable air movement through openable windows, extractor fans, or, in the case of larger buildings, a mechanical ventilation system. Some form of ventilation in a building is essential to remove moisture from kitchens, toilets and bathrooms, and to provide fresh air for occupants and to keep them cool in summer. The key factor in determining the ventilation heat loss in a building is the *ventilation rate*, which can be specified as the number of complete air changes that take place per hour (ACH). A typical rate is 0.5 ACH, meaning that it will take two hours for the air to be completely replaced by new, incoming air. If the volume of a house is V m3, and the air change rate is n ACH, then the total amount of air passing through it per hour will be n × V [m3]. The total ventilation heat loss Qv follows
$Q_v = 0.33 \times n \times V \times \Delta T$ [in Watts] with the heat capacity of air is 0.33 [Wh/(K.m^3)].

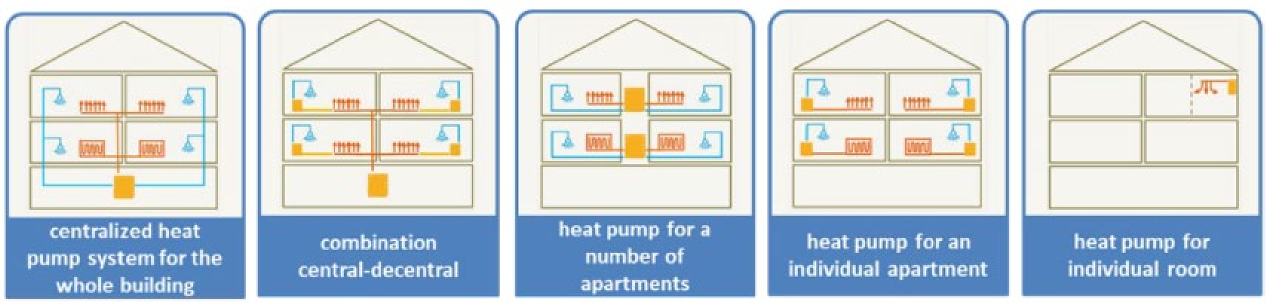
Heat loss can also be reduced by recovering some of the heat from ventilation air before it is released. Many large buildings use mechanical ventilation driven by electric fans. One way of reducing ventilation heat loss is to use mechanical ventilation with heat recovery (MVHR), which involves allowing warm outgoing air to preheat cold incoming air. This can be done by passing both air streams through a heat exchanger. They must be installed in buildings that are airtight to start with, otherwise, any attempt to pump air around the system may just increase the flow of air through unwanted air infiltration paths. Energy-recovery ventilation significantly reduces

Box 13 Heat pumps

A Heat pump is a device that uses a small amount of energy to move heat from one location to another. Heat pumps are typically used to pull heat out of the air or ground to heat a home or office building, but they can be reversed to cool the building. One biggest advantages of a heat pump over a standard heating, ventilating and air conditioning (HVAC) units is that there is no need to install separate systems to heat and cool the building. Heat pumps can provide space heating and cooling and hot water heating,

There are various types of heat pumps used in buildings, depending on sources and sinks used. For air source heat pumps (ASHP), air is the fundamental heat source. Air source heat pumps consist of air-to-air or air-to-water heat pumps. Water-source heat pumps (WSHPs) use water as a heat source and include water-to-air and water-to-eater pumps. Water can be groundwater extracted from wells or surface water extracted from ponds, lakes, or rivers. Ground source heat pumps use he ground is widely used as a heat source and sink in heat pumps. During the heating season, a GSHP can move heat taken from the ground and apply it to a building. In the cooling season, this process is reversed, as the building's excess heat is moved back to the ground to provide air conditioning. Water has a higher heat capacity than air, so, WSHP have a higher efficiency (with a COP of up to 3 or 4.5) than ASHP (with COP of 2 to 3.5). Due to the relative stability of ground temperature, geothermal heat pump systems are inherently more efficient than other heat pumps with COP in the range pf 3.8-5.0 *. AHSP have the lowest investment cost (per kW) but heating capacity and COP may decrease under cold climates. WSHPs have higher COP but water availability restricts the use of WHSP. GSHPs have the highest COPs and are more suitable in colder climates, but investment cost is higher.

Apart from type of heat pump, systems can be classified according to the level the integration in the building is realized.



The central heat pump system for the whole building, both for space heating and hot water, or heating and hot water separately. In case of large buildings, more than 1 heat pump may be necessary to meet the required heating capacity (cascade solution). Each of the modalities have their pros and cons. More decentralised systems have higher investment but also lower distribution losses. When retrofiring buildings, some variants may be easier to implement than others.

Sources: a) *Heat Pumps in Multi-Family Buildings for Space Heating and Domestic Hot Water, Annex 50 HPT-TCP, International Energy Agency* (IEA, 2022), b) *How Heat Pumps Work,* https://home.howstuffworks.com/home-improvement/heating-and-cooling/electric-heat-pumps-existing-tech-news.htm, c) *Heating and Cooling With a Heat Pump,* https://natural-resources.canada.ca/energy-efficiency/energy-star-canada/about/energy-star-announcements/publications/heating-and-cooling-heat-pump/6817; d) *The Use of Ground Source Heat Pump to Achieve a Net Zero Energy Building,* by Agostino, D. et.al in: Energies 2020, 13, 3450,

* The COP is defined as the relationship between the power (kW) that is drawn out of the heat pump as cooling or heat, and the power (kW) that is supplied. The COP usually exceeds 1, especially in heat pumps, because, instead of just converting work to heat (which, if 100% efficient, would be a COP of 1), it pumps additional heat from a heat source to where the heat is required. Most air conditioners have a COP of 2.3 to 3.5. Less work is required to move heat than for conversion into heat, and because of this, heat pumps, air conditioners and refrigeration systems can have a coefficient of performance

the energy use the coldest winter months and hottest summer months) owing to the large outdoor-indoor temperature differences.

The TEESB project will promote the use of insulated pipes and ducts. Compared to the use of boilers and chiller option, the use of heat pumps (providing for heating, cooling and hot water) allows for larger energy efficiency. Thus, it is assumed that the baseline of gas boiler (for space and hot water heating) and chiller (for cooling) is replaced by an advanced ground source heat pump system in the case of the office building and individual air source heat pump system in case of the apartment building[24].

Currently, the apartment occupants are charged per square meter of floor space, irrespective of their energy-for-heating use. Temperature valves need to be installed on room heat radiators (to finetune heat supply to actual demand). In the case of (partly) central systems, apartments or office departments need meters to be installed to be able to measure the heat supplied for each apartment or office department, By using an automated heat control (AHC) system it is possible to use 'compensated' control whereby the circulating water temperature (heated in the central boiler system that serves a group of buildings) is modulated according to the weather, reducing heat output when the weather is mild and increasing it when it is cold[25]. EMIS (energy management information systems) are the broad and rapidly evolving family of tools that monitor, analyse, and control building energy use and system performance. The data generated from EMIS tools enable building owners to operate their buildings more efficiently and with improved occupant comfort by providing visibility into and analysis of the energy consumed by lighting, space conditioning and ventilation, and other end uses. A building automation system (BAS) can be used to control building heating, ventilation, and cooling systems (and in some cases, building lighting and security systems. The BAS controls indoor temperature, humidity, ventilation, and lighting conditions. EMIS tools such as energy information systems (EIS), fault detection and diagnostics systems (FDD), and automated system optimization tools (ASO) supplement the BAS to facilitate analysis and management of building performance, including energy, comfort conditions, and ventilation. An EIS can Track, weather-normalized energy data on an interval basis (and more advanced versions are integrated with the BAS). An ASO continuously analyses and modifies BAS control settings to optimize heating, ventilation and cooling energy usage while maintaining occupant comfort. A FDD identifies abnormalities in the heating, ventilation and cooling systems or equipment performance and in some instances can isolate the root cause of anomalies. In the Project is proposed that EMIS is installed in two (new) pilot office buildings.

All the measures mentioned above (better energy performance of the building envelope, triple-glazing windows, heat recovery in ventilation) will reduce the energy loss, , of the building or contribute to using energy more efficiently, and will reduce the associated greenhouse gas emissions. Energy consumption in Turkmenistan's buildings is based on natural gas, whether direct use or in the form of natural gas used for power generation. The remaining energy consumption (after the implementation of NZEB technologies) must be compensated for by using renewable energy. It is assumed that a PV system can supply (the larger part of) the electricity demand of the heat pump. Thus, the emissions by the remaining gas and electricity are compensated for to a large extent, which leads to having a 'nearly zero emission building',

Box 14 provides the energy-relevant characteristics and an estimate of the energy consumption for heating, ventilation and cooling) of the reference residential building and one with NZEB options and Box 15 presents the reference office building and the case with NZEB options. The boxes show the calculated energy savings that can be obtained for heating (resulting in savings of direct natural gas use) as well as cooling and ventilation (resulting in electricity savings). Since most of all electricity is generated from natural gas, saving power results in savings in natural gas). It should be noted that in cases where the PV can produce more electricity than the energy needed for heating, cooling or ventilation, in which case it is assumed that the access power can be delivered to the grid (and thus the corresponding CO_2 emission reduction can still be accounted as compensation for energy consumption, albeit outside the building).

---

44 Ground-source heat pumps are more efficiency than air heat pumps but investment cost is also relatively higher, For an apartment building a range of onions are possible from central to individual, as explained in **Box 13**.

Energy storage systems and the associated energy conversion equipment are not considered here, as they make NZEBs more complex and require additional investment. In cases were peak demand exceeds the capacity of the heatb pump system (e.g. very cold days and/or without sufficient sunshine), the heat is assumed to be provided by the gas boiler systems in the vicinity of the pilot buildings (micro district heating). Electricity will always be guaranteed as all buildings are grid-connected.

25 Air temperature may be sensed either (a) within the room(s) supplied or (b) in the room extract ductwork. Similarly, in cooling with central chillers, the supply of chilled water to the battery, is based on an air temperature measurement from a sensor located (a) within the supplied room space, or (b) in the air extract ductwork. In the EERB project, it was found that the installation of AHC systems yielded heat energy savings of about 18% in heating and 3% in cooling.

Box 14 Calculation of energy flows (heating, cooling, ventilation) in a pilot residential apartment building (reference case and with NZEB options)

Height floor (m)	2.95	Total height	17.7	(4 floors + attic +_basement)		
Area; one floor)	1350	Wall area	3,717	Total floor	8100	m^2
Length (m)	90.0	Entrance	280	Apart.space	5308	m^2 (stairway space is 92 m^2)
Width (m)	15	No. apartments	30	Volume	23895	m^3

Energy transmittance values						
		Current values		*NZEB values*		
	Area (m2)	*U-value W/(m2.K)*	*Contribution W/K*	*U-value in NZEB*	*Contribution W/K*	
Wall	3,052	0.44	1635.5	0.2	743.4	U*area (wall w/o window)
Roof	1,350	0.33	445.5	0.15	202.5	U*area (roof)
Basement	1,350	0.6	810.0	0.4	540.0	U*area (basement)
Window	385	1.7	654.0	0.86	330.8	U*area (window)
- % of wall	10%					% of wall area
Vestibule	280	2	560	1.0	280	vestibule
Envelope	6,417	*0.64*	4105.0	*0.33*	2096.7	a (=sum of above)
Energy losses/gains						
Degree.hours [K.hr]			2801		2801	q (see footnote)
Energy flow- convection [MWh/yr]			276.0		141.0	$d=c*(a+b)*24/1.10^6$
Energy flow - ventilation			188.4		188.4	e=n*f*c*V*24/1.106
ACH (n)	0.35			0.35		n: air exchange per hr
air heat flow	0.34					f: 1204*1002/3600
Heat recovery ventilation			0	60%	75.4	e2=(1-60%)*e
Energy flow (MWh/yr)		Total	464.4		216.3	
Heating and cooling needs						
Heating	Heat		375.4		174.9	i, see footnote
	Free heet		48.4		48.4	j, see footnote
	Hot water need		114		114	k, see footnote
					0	
Heating need	18%	w/o AHC	**500.1**	with AHC	**240.7**	m=(i-j)*(1+18%)+k
Cooling	Heat gain		89.0		41.5	c, see footnote
	Free heat		18.4		18.4	o, see footnote
Cooling need	3%	w/o AHC	**110.6**	with AHC	**59.9**	p=(n+o)*(1+3%)
Total			***610.8***		***300.6***	MWh/yr
Energy consumption						
Gas consumption			556		0	MWh_{th}
Efficiency burning, boiler		90%	2000	90%	0	GJ
Share heat pump				100%	241	MWh
			73217		0	m3
			110.0		0.0	tCO_2
Electricity consumption						
IPLV, chiller; COP heat pump		3.8	29.1	3.5	85.9	MWhe
			20.2		59.5	tCO_2
Emissions heating, cooling, ventilation			130.2		59.5	tCO_2/yr

Renewable energy (solar)		
Solar PV	298.36	m^2
Size	66	kW
Electr production	97.6	MWh/yr
Net electr production	78.1	MWh/yr
Emissions avoided	54.1	tCO_2/yr

Summary savings and substitution		
EE savings	70.7	tCO_2/yr
	357.0	MWh gas/yr
Substit. PV	54.1	tCO_2/yr
	273.32	MWh gas/yr
Total	124.8	tCO_2/yr
	630.32	MWh gas/yr
Net emissions	5.4	tCO_2/yr

Box 15 Calculation of energy flows (heating, cooling, ventilation) in a pilot office (public) building (reference case and with NZEB options)

Height floor	2.95	m	No. of floors	6	(5 floors plus basement)
Area; one storey	1440	m^2			
Average length	37.9	m	area (m^2)	8640	
Volume	25488	m^3	Office area	6544	(excl. 92 m^2 stairway area)

Energy transmittance values						
		Current values		*NZEB values*		
	Area (m2)	*U-value W/(m2.K)*	*Contribution W/K*	*U-value in NZEB*	*Contribution W/K*	
Wall	1466.3	0.44	645.2	0.2	293.3	U*area (wall w/o window)
Roof	1440	0.33	475.2	0.15	216.0	U*area (roof)
Basement	1440	0.6	864.0	0.4	576.0	U*area (basement)
Window	789.6	1.7	1342.3	0.86	679.0	U*area (window)
- % of wall	35%					% of wall area
Vestibule	280	2	560	1.0	280	vestibule
Envelope	5415.9	*0.72*	3886.6	*0.38*	2044.3	a (=sum of above)
Energy losses/gains						
Degree.hours [K.hr]			2801		2801	q (see footnote)
Energy flow- convection [MWh/yr]			261.3		137.4	d=c*(a+b)*24/1.10[6]
Energy flow - ventilation			287.1		287.1	e=n*f*c*V*24/1.106
ACH (n)	0.5			0.5		n: air exchange per hr
air heat flow	0.34					f: 1204*1002/3600
Heat recovery ventilation				60%	114.9	e2=(1-60%)*e
Energy flow (MWh/yr)		Total	548.5		252.3	
Heating and cooling needs						
Heating	Heat		443.3		203.9	i, see footnote
	Free heet		82.4		82.4	j, see footnote
	Hot water need		60		60	k, see footnote
					0	
Heating need	26%	w/o EMIS	**514.7**	w EMIS	**181.4**	m=(i-j)*(1+26%)+k
Cooling	Cooling		105.1		48.4	c, see footnote
	Free heat		47.4		47.4	o, see footnote
Cooling need	12%	w/o EMIS	**170.9**	w EMIS	**95.8**	p=(n+o)*(1+12%)
Total			***685.5***		***277.2***	MWh/yr

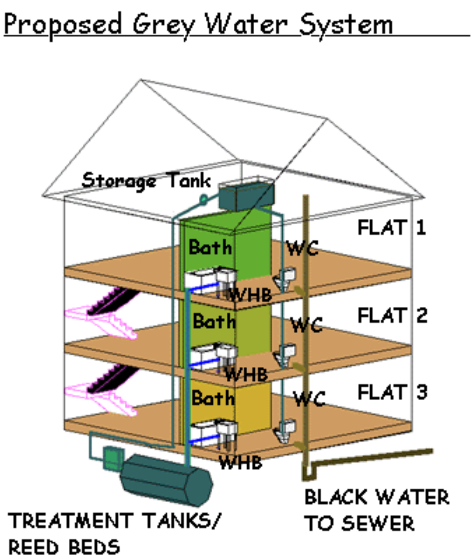
Energy consumption					
Gas consumpption		572		0	MWh_{th}
Efficiency boiler	0.9	2059	90%	0	GJ
Share heat pump			100%	181	MWh_{th}
		75346		0	m^3
		113.2		0.0	tCO_2
Electricity					
IPLV, chiller; COP heat pump	3.8	45.0	4.5	61.6	MWh_e
		31.2		42.7	tCO_2/yr
Emissions heating, cooling, ventilation		144.4		42.7	tCO_2/yr

Renewable energy		
Solar PV	207.95	m^2
Size	46	kW
Electr production	68.0	MWh/yr
Net electr production	54.4	MWh/yr
Emissions avoided	37.7	tCO_2/yr

Savings and substitution		
Savings	101.7	tCO_2/yr
	513.6	MWh gas/yr
Subst PV	37.7	tCO_2/yr
	190.50	MWh gas/yr
TOTALS	139.4	tCO_2/yr
	704.09	MWh gas/yr
Net emissions	5.0	tCO_2/yr

The estimates in this Annex do not include the energy consumption of electric appliances used by households and in offices, such as refrigerators and freezers, washing machines and dryers, lighting products, computers, printers, etc. The introduction of energy-efficient appliances with minimum performance standards and labelling has been the subject of separate GEF-supported projects in many countries.

The main source of water (84%) for Turkmenistan is the Amudarya River, whose water use is controlled by multilateral agreements, which allocate to Turkmenistan 22 billion m^3, or 36% of Amudarya flow per year. The remaining water resources are groundwater (5%) and other rivers (11%). Most of the water is used for irrigation (about two-thirds, but half is lost between delivery and withdrawal) and households use 2%. Efficient water use in rural areas and for agriculture has been the focus of the UNDP/GEF-supported projects, such as 'Energy efficiency and renewable energy for sustainable water management in Turkmenistan' and the recent "Supporting climate resilient livelihoods in agricultural communities in drought-prone areas of Turkmenistan'



Also, in urban areas water can be used more efficiently. One way is by using more water-efficient appliances and devices (toilets, showerheads, efficient dishwashers and washing machines). Another way is to recycle wastewater. There are two kinds of wastewater in domestic buildings: greywater and blackwater. Blackwater comes from toilets, contains harmful pathogens, and cannot be reused unless treated in a dedicated sewage facility. Greywater (typically 50-80% of wastewater in a building) is generated from domestic activities such as laundry, dishwashing, and bathing. It can be recycled and reused for watering the garden or flushing toilets after some form of treatment such as filtering and disinfectant to remove bacteria and other biological material. Reusing greywater can save up to 30-50% of water use in a residential building. In the case of the pilot buildings, the grey water system is assumed to be applied in the office building where building management can more easily absorb the system in comparison with individually owned apartments. However, if the results of the pilot are positive the options could be extended to future NZE apartment buildings.

2.3 Financial analysis of NZEB buildings

The financial impacts of implementing NZEB options have been calculated for the residential apartment building (see Box 26) and the office building (see Box 27) by assuming the *incremental* investment cost of energy efficiency options (e.g. wall insulation with higher thickness and the wall insulation implemented in the reference case; hear pump replacing boiler and chiller) and *add-on* investment cost of implementing heat recovery in ventilation (HRV) and solar energy. The results of the cost estimates are given in Box 28.

It should be noted which option will be applied and to what extent will depend on a detailed design and feasibility analysis as part of the overall building construction design. The numbers on energy savings and investments are indicative only and meant to give the order of magnitude of the energy saving and financial implications to be able to assess the direct emission reduction of the TEESB's pilot buildings and level of GEF and co-financing investment support (discussed in Annex H).

Box 16 Estimated investment cost of the TEESB pilot buildings (residential apartments; public)

		Residential (30 apt.)	Office building	Residential building	Office building
	Incremental cost (USD/unit)	*Incremental cost*		*Full cost*	
Increase U-value, wall	0.6 per m^2/cm	11,151	4,399	34,683	16,662
Increase U-value, roof	0.6 per m^2/cm	9,356	9,936	13,946	16,363
Increase U-value, basement	0.60 per m^2/cm	4,050	4,320	15,296	16,363
Increase U-value, windiw	16 per m^2	6,155	12,633	33,084	67,903
Incremental cost heat pump	See footnote price differenc	89,835	82,314	114,510	127,828
Heat recovery ventilation	15 per m^3/h	106,631	162,486	106,631	162,486
BAS (with AHC), meters		20,000		20,000	
EMIS(with AHC), meters			35,000		35,000
Solar PV	1250 per W_p syst.	82,500	57,500	82,500	57,500
Grey water recycling			35,000		35,000
Vestibule	1700 USD	1700	1700	1700	1700
Contingency and other cost		6,622	6,712	7,651	8,196
Subtotal		**338,000**	**412,000**	**430,000**	**545,000**
GEF INV **TOTAL** (one 5-floor building + one office)			**750,000**		
Co-financing (baseline heating with boiler/chiller; current building codes)				92,000	133,001
Co-financing (construction only)				12,058,000	12,826,999
Co-financing INV (for all construction, incl. baseline energy efficiency and supply)				**12,150,000**	**12,960,000**

Notes for Box 26, Box 27, and Box 28:

- Data on U-values and incremental costs based on NZEB reports Romania and Poland (BPIE, 2012) and www.globalpanel.com, assuming g thickness increase of insulation materials of 5 cm (wall, 11.5 cm (roof), 5 cm (basement) and changing from double to triple glazing. The total full cost of insulation is USD 10.33 per m² to which 10% installation cost is added. Source: (https://glavsnab.net/bazaltovaya-vata-rockwool-venti-batts-1000kh600kh100-mm-4-shtuki-v-upakovke.html?specification). Full cost of window id USD 86 per m² based on https://1-ok.com.ua/tceny/steklopakety-tceny#!/tproduct/492634085-1663184494269)
- HRV cost based on values mentioned in above-mentioned NZEB reports with m³/h value = volume building*85%
- Cost of automated heating and cooling control, meters, USD 20,000. Cost of additional EMIS features (energy information system, EIS, and fault detection, diagnostics, FDD, USD 15,000). Based on *Proving the Business Case for Building Analytics,* Lawrence Berkeley National Laboratory (2020)
- Free heat based and residential building hot water needs: see Box 21. Office hot water needs: 5 litre per person, 654 employees (office space of 10 m² per employee).
- For solar PV energy generation and cost data of solar PV systems (per kW), see Box 24
- Grey water recycling and re-use cost is average of prices mentioned in a) *Feasibility and impact of greywater recycling in four types of buildings in Sharjah, United Arab Emirates* (Tayara, et.al., 2020), in IOP Conf. Series: Earth and Environmental Science 725 (2021) 012009; b) *Greywater Reuse System Design and Economic Analysis for Residential Buildings in Taiwan* (Yuan, et.al.; 2016), in: Water 2016, 8, 546; doi:10.3390/w8110546; c) *Feasibility of Recycling Grey-water in Multi-Storey Buildings in Melbourne* (Imteaz & Shanableh; 2012; www.wsforum.org); d) *Feasibility study grey water use* (Jiang et.al., Proceeding 11th Conference on Science and Technology)
- Chiller baseline cost based on data provided in Annex of the UNDP/GEF project document "Super-efficient technologies and thermal comfort in buildings, India" (2021). The cost of a boiler is assumed to be USD 155 and 120 per kW respectively. Including 10% installation cost, this gives USD 27143 for the apartment building and USD 250,0337 for the office building,
- The cost of GSHP (for the central office building system) is based on USD 1200/kW plus 10% installation cost. Data based on comparison of various sources, including a) http://2050-calculator-tool-wiki.decc.gov.uk/, b) www.kensacontracting.com/market-sectors, c) *Implementing Nearly-Zero Buildings (nZEB)*, Romania and Poland reports, BPIE (2012), d) https://www.epa.gov/rhc/rhc-multi-unit-housing. The cost of air heat pump systems for an apartment is based on USD 3,470 plus 10% installation cost. Source: https://limitenergy.ru/sila-am-18-i-evi-invertornyj-teplovoj-nasos/. The incremental cost of the heat pump system is its investment cost minus the cost of the alternative gas boiler-chiller solution.
- To determine co-financing INV, building construction cost are assumed to be USD 1500 per m² of total floor space. Assumption based by comparing sources, incl. https://economictimes.indiatimes.com/industry/services/property-/-cstruction/construction-cost-in-mumbai-highest-across-india-chennai-hyderabad-lowest-report/articleshow/81424837.cms; https://proest.com/construction/cost-estimates/apartment-complexes/; https://www.levelset.com/blog/cost-to-build-an-apartment-complex/; and https://www.checkatrade.com/blog/cost-guides/how-much-cost-build-flats/

.