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Interventions for increasing energy efficiency in hospitals (Protocol).
Cochrane Database of Systematic Reviews 2024, Issue 3. Art. No.: CD015693.
DOI: 10.1002/14651858.CD015693.

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Interventions for increasing energy efficiency in hospitals

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Editorial group: Cochrane Central Editorial Service.
Publication status and date: New, published in Issue 3, 2024.

Citation: Chen-Xu J, Kislaya I, Fernandes RM, Carvalho J, Blanco-Rojas BJ, El-Omrani O, Miotto E, Čič K, Boto P, Viegas S. Interventions for increasing energy efficiency in hospitals (Protocol). *Cochrane Database of Systematic Reviews* 2024, Issue 3. Art. No.: CD015693. DOI: 10.1002/14651858.CD015693.

ABSTRACT

Objectives

This is a protocol for a Cochrane Review (intervention). The objectives are as follows:

The main objective is to assess the effectiveness of interventions designed to increase energy efficiency in hospitals.

BACKGROUND

The health sector today faces many cross-cutting challenges that affect countries worldwide, most notably climate change (Watts 2019). This is expected to overburden health systems, compromising access to health care and resulting in financial and organisational constraints (Sowada 2019).

Attention has recently shifted to the impact of human activities on the environment and how it affects future generations, with an expected increase in health inequities. This means that the health sector should answer to the need to adapt to the climate change scenario but also to have a role in limiting global warming, such as reducing emissions and energy consumption, and its effects, by adopting cleaner energies.

Overall, buildings represent about 35% of global energy consumed, leading to almost 40% of energy-related carbon dioxide emissions, thereby playing an important role in cost-effective reduction of carbon footprint and sustainable transformation (Li 2022). Buildings also consume a large amount of water throughout their life cycle, in addition to the energy required for its supply and use, which can represent up to 3% of the national electricity consumption. The interplay between water and energy lies in maintenance of infrastructure and equipment in water systems, such as heating water pumps (Rothausen 2011).

The healthcare sector has an environmental impact that ranges between 1% and 5% of total global impacts (Lenzen 2020). This value can surpass 5% in the national context, such as in the Netherlands, where healthcare institutions contribute to 7% of the total carbon footprint (Friedericy 2019).

There is a need for a baseline assessment at the local level of buildings of healthcare organisations, whether in the conception of new buildings or the maintenance of existing ones. Hospitals have one of the largest ecological footprints as the most energy-intensive buildings, serving thousands of employees, patients, and visitors continuously, differing from smaller clinics and primary healthcare centres, which present significantly lower energy costs due to their dimension and activity (Zaza 2022). Hospitals use significant amounts of energy for equipment such as lighting in operating rooms, medical devices (e.g. magnetic resonance imaging), air exchange, and filtration (García-Sanz-Calcedo 2019). Moreover, they release potentially harmful pollutants, including carbon dioxide and methane (Serghides 2020; Zhang 2022). On the other hand, heating, water, and electricity make up around 40% of the carbon footprint of a health system (Pichler 2019), only followed by transport (~22%) and pharmaceuticals (~11%). As such, improving energy management within hospitals has emerged as a priority for health institutions in order to reduce their environmental impact.

Description of the condition

Not investing in energy efficiency measures might contribute to the climate change phenomena and, consequently, impact human health.

Efforts have been made to invest in hospitals, turning them into more resilient, sustainable, and environmentally friendly institutions (Corvalan 2020), without compromising medical care. Measures improving energy efficiency, water use, and waste management have been shown to greatly contribute to reducing the carbon footprint of hospitals (Kaplan 2012; McGain 2014; Ryan-Fogarty 2016; Watts 2019), which also require institutional commitment (Pisters 2017). An Italian study further supports the importance of the role of human resources and their behaviour in relation to the environment, through raising awareness and implementing ecological practices among employees (Pinzone 2016).

Energy efficiency measures have been shown to save hospitals over USD 55,000 annually and to result in a reduction of emission of around 142 megatons of greenhouse gases (Langstaff 2017). Other researchers carried out an analysis of hospitals in order to benchmark the energy spending and calculate the potential margin of savings (González González 2018). Despite existing measures that largely focus on improving energy saving, the number of studies documenting their effect on energy efficiency in healthcare settings is still limited.

Description of the intervention

There are two principal types of energy needs in hospitals: thermal energy and electricity. Hospitals have substantially higher thermal and electricity requirements than other types of commercial buildings because they work 24 hours a day, 7 days a week, all year. Thermal energy is mainly used for heating and air conditioning of rooms, sanitary water production, sterilisation and laundry, and kitchen services. Electricity is used mainly to power medical equipment, lighting, refrigeration, air treatment, lifts, and the operation of computerised and security systems (Alexis 2013; Zaza 2022).

There are several effective energy saving strategies at the hospital level, of lesser or greater complexity, which can reduce the amount of energy consumed and carbon emissions and increase energy efficiency. When implementing energy saving strategies, the following must be considered: energy needs, current energy consumption data, the current cost of covering those consumptions and the resultant environmental impacts, pre-existing infrastructure, existing technical and financial resources, and weather conditions (hospitals located in the coldest zones have lower energy consumption than those in the warmest zones, according to one study) (Alexis 2013; Čongradac 2012; Cygańska 2021).

How the intervention might work

The following are initiatives that could potentially lower energy consumption.

- Audit energy consumption. This allows hospitals to set a baseline for energy consumption, which permits an energy benchmark and the defining of indicators that enable regular monitoring of energy consumption (Dadi 2022).
- Use of energy-efficient light bulbs, mainly light-emitting diodes (LED). These depend on the number of lamps, lighting hours and their efficiency (ratio between light output and electric power input). This investment would have an estimated turnaround of eight years, not considering savings in maintenance and the life of the lamps (Gordo 2011; Zaza 2022).
- Use of transducers such as sensors and actuators. One classic example is the use of motion sensors to adjust the heating/cooling system and/or lighting according to the occupation

of the room. This strategy is more efficient in diagnostic and treatment rooms than in patient rooms, because the former are only used during working hours. Another example is the monitoring of carbon dioxide in the room and in the heating, ventilating and air conditioning (HVAC) system to avoid over ventilation when carbon dioxide levels are low, making ventilation more efficient and reducing energy costs. This is used in demand-controlled ventilation (DCV), a ventilation rate control practice that provides the amount of each space based on real-time demand (Čongradac 2012; Delgado 2021).

- Use of energy monitoring systems (EMS), which allow tracking of energy usage in the building(s). These are applied to minimise the energy demand of a building's services, which include devices, lighting, temperature regulation, and water heating. EMS can be further improved with neural networks and artificial intelligence, among other technological applications. Despite the initial high investment, energy efficiency can be increased by 36% (Čongradac 2012; Papantoniou 2015; Prada 2020).
- Infrastructural changes, including the addition of thermal insulation of exposed external walls (Prada 2020; Zaza 2022), as well as replacing window framings and the use of blinds (Čongradac 2012; Gordo 2011; Prada 2020), which improve temperature regulation of spaces, thereby reducing the need for additional measures such as air conditioning or heating, and in turn minimise energy losses.
- Improvement of medical equipment or technologies such as magnetic resonance imaging, laboratory equipment, and elevators. Utilising smarter technology allows for automation and decreasing energy consumption in periods with no activity (Gordo 2011; Prada 2020).
- Use of solar collectors for sanitary hot water production (Zaza 2022). A good extension of solar collectors allows utilising the energy captured for water heating, thereby reducing energy consumption (Atienza-Márquez 2022).
- Replacement of inefficient boilers and regular maintenance of central heating boilers (Gordo 2011; Zaza 2022). Newer models consume less energy while providing the same or better performance. Concomitantly, regular maintenance of central heating boilers is needed (Hendron 2013).
- Implementation of efficient HVAC systems. These systems have three main functions: heating to keep the temperature controlled on the coldest days; ventilation, to renew the ambient air, remove its impurities (including bacteria, fungi, and virus), and control its temperature; and air conditioning, to guarantee the cooling of the room and to control the humidity of the environment. The efficiency of these systems depends on the energy sources used, the correct sizing of the system, the existence of energy recovery devices and their integration with systems that control energy usage (Delgado 2021; Koulamas 2017).
- Use of heat pumps (Prada 2020). Together with good thermal isolation, the use of heat pumps significantly reduces the natural gas consumption used for water heating and on-site greenhouse emissions (Atienza-Márquez 2022).
- Use of renewable sources of energy for heat, cooling, and electricity generation, such as solar photovoltaic energy, solar thermal energy, biomass, and geothermal energy (Prada 2020). These reduce costs and carbon emissions due to their lower cost and stable and independent source of energy, contributing to the resilience of hospitals (Duraivelu 2021; Zaza 2022).
- Combined systems: simultaneous production of several energy outputs (electric, heat and cold) from one energy source, thereby minimising energy losses. There are two types of combined systems: cogeneration, which produces electricity and heat; and trigeneration, which produces electrical energy, thermal energy in the form of heat, and thermal energy in the form of cold. Renewable sources of energy can be used. Cogeneration has been shown to reduce 8% to 25% of energy consumption in hospitals (Suszanowicz 2019; Szklo 2004).
- Educational interventions, including training and campaigns aimed at workers (Islam 2022). Healthcare professionals play an active role in reducing energy consumption, mainly through behavioural change, such as turning off the lights or devices when not utilised (Azizi 2018). Reductions of at least 13% in electricity consumption have been associated with interventions aiming at behavioural change of NHS staff (Sawyer 2021).

Why it is important to do this review

Many manuals and reviews have been published both by regulatory entities and academic journals focusing primarily on either green hospitals in general (McGain 2014), or on the energy efficiency of hospitals (US Department of Energy 2021; USAID 2009). There are already some reviews published on the topic, including a systematic review, which focused primarily on mapping the interventions across single and multicentre studies (Psillaki 2023), and which will serve as a baseline for our paper.

Despite the existing international and European energy regulations and certification for buildings, and an increased awareness of the need for improving hospital buildings, energy management in hospitals is still diverse and might vary between countries, with different strategies and goals defined. There is a need to appraise the current situation regarding environmental practices that can impact energy efficiency, and to understand which measures are more efficient so that hospitals worldwide can implement evidence-based measures resulting in better outcomes in terms of expenditure and impact on the environment, especially after the pandemic, with an intent to build back better, greener, more digital, and more resilient.

We therefore propose a systematic review of interventions aimed at increasing energy efficiency in hospitals. If possible, a secondary objective will consist of analysing the potential margin of savings for each intervention.

OBJECTIVES

The main objective is to assess the effectiveness of interventions designed to increase energy efficiency in hospitals.

METHODS

Criteria for considering studies for this review

Types of studies

We will consider the following types of studies for the review.

- Non-randomised studies: any quantitative study that estimates the effectiveness of an intervention that does not use randomisation to intervention groups. These include case-control studies, cohort studies, controlled before-and-after

studies, interrupted-time-series studies (ITS), and quasi-experimental studies (Reeves 2022). Controlled before-after studies should include more than one site in each of the intervention and control groups to avoid confounding, and the sites should be broadly comparable, and with contemporaneous measurements. Interrupted time series should have a clear intervention point and at least three data points available before and after the intervention.

- Randomised trials, where comparison groups were established by random allocation.
- Trial registers from public records of planned research projects.

Studies must have not only abstract, but also full-text. We will also search unpublished data and other grey literature, which might contain use cases or case analyses, namely national reports on energy consumption.

We will not include other studies, such as economic research studies. We will capture only what is measured by the included study designs.

Types of participants

The population consists of both public and private hospitals and clinics, located in any part of the world. General hospitals, specialised hospitals, and university hospitals that have been subject to the interventions mentioned above are also eligible.

We will exclude primary healthcare centres and other governmental healthcare institutions as their main activities and energy consumption differ greatly from that of hospitals (Zaza 2022).

We will include studies of other types of health institutions if hospitals are at least one-third of the sample, and if there is a subgroup analysis or any other disaggregated data for the analysis of the specific subgroup of hospitals.

Types of interventions

We will include the following interventions in the review.

- Use of renewable energies, including photovoltaic and solar panels, geothermal, and wind energy.
- Use of technologies to manage electrical load (e.g. LED lighting, variable speed drives on medical air compressors, etc.).
- Use of technologies that improve building performance (e.g. controls and building automation systems, transducers for improving HVAC systems, energy monitoring systems).
- Infrastructural measures: thermal insulation of exposed external walls, window framings and blinds.
- Use of technologies to manage consumption of water, including central boilers or heat pumps.
- Combined systems: simultaneous production of several energy outputs (electric, heat and cold) from one energy source. This may be classified as co- and trigeneration (Neacsa 2022).
- Improvement of medical equipment or technologies such as magnetic resonance imaging and laboratory equipment.
- Educational interventions, including training and campaigns aimed at workers.

We will compare the energy consumption after the intervention with the baseline status (before the intervention) and with hospitals with similar characteristics. The application of these measures might vary due to climate and geography, as countries with less solar exposure might not adopt panels, and countries with geothermal energy might adopt this source. Likewise, we will also analyse water consumption and compare it with other hospitals.

If possible, we will also compare carbon footprint and energy-related expenditure after the intervention with the baseline footprint and expenditure of similar hospitals considered as part of the control group.

In the case of co-interventions, we will investigate if the intervention effect is modified by the addition of the supplementary intervention through subgroup analysis. We will create groups according to the typology of intervention applied, as described above. If there are several interventions and outcomes can be adjusted and reported separately, these will be accounted for in each intervention group. In case there are co-interventions and these cannot be separated, we will have a separate miscellaneous group ('package of interventions') to address this.

We will also attempt to differentiate between energy (oil, electricity, and gas) and water consumption, if this is specified.

As we are focused on the hospital as a whole, sector-specific interventions within the hospital will not be analysed, which are also limited in terms of overall environmental impacts of the hospital.

Types of outcome measures

Primary outcomes

1. Energy consumption measured in the following domains (if possible):

- electricity;
- natural gas;
- oil.

This refers to the total amount of electricity, gas, or oil consumed by the hospital, including energy used to feed the combined heat and power plant and energy used by the hospital for processing purposes (e.g. cooking, laundry) (Tennison 2021). These are measured in kiloWatt-hour (kWh), Tonne of Oil Equivalent (TOE) or equivalent. These will be converted to kWh to allow comparability by applying the conversion rate of: 1 TOE = 11,630 kWh.

2. Water consumption measured in cubic metre (m^3), litre (l), or kilo (kg), being converted to m^3 for the sake of comparability.

Secondary outcomes

1. Energy-related expenditure measured in euros. Expenditure and cost savings might be reported in other units. We will therefore consider the exchange rate of the year the study was conducted and convert it to euro. If the unit is expressed in currency per kWh or per built-surface area, we will attempt to convert to the euro if possible. If this is not possible, we will additionally report this information in our summary of results.

2. Emissions of greenhouse gases measured or converted to tonnes of carbon dioxide (CO_2) equivalent (tCO_2^{-e}) for greenhouse gases.

If we are presented with multiple measures of the same outcome of interest throughout time, we will first attempt to present a summary effect over all time points, or choose one time point that is the most appropriate one, depending on the methodology described in the study. If different methodologies measure the same outcome, we will extract both and then adopt the most common methodology utilised across studies to ensure lower discrepancies between studies.

As energy efficiency is inferred by measuring consumption, increased weighting will be assigned to those studies that follow established best-practice protocols and guidelines for Measurement and Verification of Energy Efficiency (US Environmental Protection Agency 2019), including but not limited to the International Performance Measurement and Verification Protocol (IPMVP), the M&V Guidelines: Measurement and Verification for Federal Energy Projects, and the ASHRAE Standards and Guidelines Activities.

Timing of outcome measurement

Since these interventions require a minimum amount of time to be measured and to understand their impact, we have adjusted the different timings to better reflect our context (US Environmental Protection Agency 2019):

- short term: up to one year from the onset of the intervention;
- medium term: one to three years after the intervention;
- long term: at least three years after the intervention.

Search methods for identification of studies

We will search databases, registries, and grey literature (e.g. international organisations and national reports). We will apply no search restrictions.

Electronic searches

We will identify trials through systematic searches of the following bibliographic databases:

- Cochrane Central Register of Controlled Trials (CENTRAL) in the Cochrane Library;
- MEDLINE Ovid;
- Embase Ovid;
- Web of Science Core Collection;
- Scopus;
- Science Direct.

We will adapt the preliminary search strategy for MEDLINE (Ovid) (Appendix 1) for use in the other databases. We will also conduct a search of ClinicalTrials.gov (www.clinicaltrials.gov), the World Health Organization (WHO) International Clinical Trials Registry Platform (ICTRP) (apps.who.int/trialsearch), and EU Clinical Trials Register (EU CTR) (www.clinicaltrialsregister.eu/ctr-search/search) for ongoing or unpublished trials.

We will search all databases from their inception to the present and impose no restrictions on language of publication or publication status.

Searching other resources

We will check the reference lists of all included studies and any relevant systematic reviews identified for additional references. We will also examine any relevant retraction statements and errata for the included studies. We will contact authors for missing data. We will also search relevant institutions' websites for information, including international organisations such as the Organisation for Economic Co-operation and Development (OECD) (www.oecd.org), WHO (www.who.int), and the following European Union institutions: European Commission (www.health.ec.europa.eu), European Parliament (www.europarl.europa.eu), and Council of the European Union (www.consilium.europa.eu), as well as health systems that publicly report such information.

Data collection and analysis

Selection of studies

The results of the search will be handled in the CADIMA platform (Kohl 2017).

Two review authors will independently screen titles and abstracts of the studies identified by the search for potential relevance. Any discordant screening and review results will be resolved by discussion between review authors or by consulting a third review author if necessary. The possible classifications for studies at this stage are: 'Yes', 'Unclear', 'No'. If at least one 'No' is selected by a review author, the article is automatically flagged for conflict reconciliation. If both review authors answer 'No', the paper will be deemed irrelevant and removed. The remaining options will allow the articles to pass to the next phase.

We will download full papers from the original journal website, when available. In case the article cannot be found, we will search alternative research websites, such as ResearchGate, which allow for direct download or full-text request from authors. As a last resort, we will contact the corresponding author by email to request the paper. If the paper is still unavailable, it will be read again to determine if it presents sufficient information to be included, otherwise it will be excluded. After retrieval, studies will be fully read to determine if all dimensions of PICO (Population, Intervention, Comparator, and Outcomes) are present.

We will group multiple reports and papers related to a single study or trial under a single reference ID.

The CADIMA platform allows for each step of the process to be recorded, facilitating the creation of the PRISMA flow diagram (Page 2021).

Data extraction and management

Four review authors (JCX, BBR, EM, JC) will independently perform study screening and selection. Two review authors (BBR, JCX) will perform data extraction.

In the case of missing or unclear information, we will contact study authors as necessary.

We will extract the following information.

- Information about the article: title, DOI, publication date.

- Methods: study design, total duration of study, number of study centres and location, study setting, and date of study (month and year), data analysis method.
- Participants: total number of hospitals, number of analysed hospitals.
- Hospital setting and characteristics: country, economic status (high-, low-income country), urban/rural/remote built-in surface area, if private/public, university hospital, number of workers, and number of departments (if possible).
- Other relevant characteristics: main existing energy sources before the study (e.g. national power grid of mixed energy, local generation and typology - aeolic, thermal, solar, among others).
- Interventions: intervention: energy efficiency measures, as defined above, comparator, and co-interventions.
- Outcomes: annual energy or water consumption.
- Secondary outcome: annual energy expenditure; CO_2 or other greenhouse gas emissions (carbon footprint).
- Any confounding factors reported.
- Funding information: any entity funding the study.
- Existing conflicts of interest of study authors.
- Information needed to assess bias: deviations from intended interventions, existence of data for key outcomes.
- Information needed to assess GRADE: baseline assessment for key outcomes.

We will extract data using a pre-designed Excel file before entering the data into RevMan (RevMan 2024). Two review authors (JCX, BBR) will then transfer the data into RevMan.

We plan to synthesise the characteristics of all studies with the relevant data described above and present these as descriptive analysis in the 'Characteristics of included studies' table in the full review. We will also include a summary table of the main characteristics. If possible, we will then convert data found in studies to a format appropriate for meta-analysis following the methods described in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2022b).

Assessment of risk of bias in included studies

Four review authors (OO, KC, EM, JC) will assess risk of bias using the Risk Of Bias In Non-Randomized Studies - of Interventions (ROBINS-I) tool for non-randomised studies (Sterne 2016), and the RoB 2 tool for randomised trials (Sterne 2019). Any disagreements will be resolved by discussion.

We will use PICO (Population, Intervention, Comparator, and Outcomes) items for risk of bias assessment. Confounding domains will mainly be hospital factors not accounted for, such as current institutional policies and yearly budget and financing, as well as other external conditions, including economic and political environment, climate and temperature, corruption, and openness to innovation (Dokas 2022; Sineviciene 2017). Co-interventions that could differ between intervention groups and that could impact on outcomes will include leadership, hospital management policies and organisational matters, existence of an Environmental or Sustainability Department, and of a formal environmental certification, among others (Langstaff 2017; Sineviciene 2017).

The ROBINS-I and RoB 2 tools consist of seven and five domains, respectively. These tools present a series of 'signalling questions'; a judgement about risk of bias for the domain, which is facilitated by an algorithm that maps responses to the signalling questions to a proposed judgement; justification of responses to the signalling questions and risk of bias judgements; and an explanation of the likely direction of bias.

The signalling questions of ROBINS-I aim to elicit information relevant to the risk of bias judgement for the domain, and work in the same way for RoB 2. The response options are: yes; probably yes; probably no; no; no information.

The ROBINS-I tool consists of the following domains.

- Bias due to confounding
- Bias in selection of participants into the study
- Bias in classification of interventions
- Bias due to deviations from intended interventions
- Bias due to missing data
- Bias in measurement of outcomes
- Bias in selection of the reported result

Based on answers to the signalling questions, we will classify judgements for each domain and for overall risk of bias as 'Low', 'Moderate', 'Serious', or 'Critical' risk of bias (Sterne 2016).

The RoB 2 tool consists of the following domains (Higgins 2022a).

- Bis arising from the randomisation process
- Bias due to deviations from intended interventions
- Bias due to missing outcome data
- Bias in measurement of the outcome
- Bias in selection of the reported result

We will classify judgements for each domain and for overall risk of bias as 'Low risk of bias', 'Some concerns', or 'High risk of bias'.

Judging a result to be at a particular level of risk of bias for an individual domain implies that the result has an overall risk of bias at least matching the same level of severity.

ROBINS-I and RoB 2 will be supported by the robvis tool (McGuinness 2020), which will allow for a risk of bias summary in graphic form, providing an overall perspective of risk of bias in the included studies.

Measures of treatment effect

We will compare the hospitals using itself as a baseline comparator and then with the implementation of the measure. For controlled studies, we will use analogous hospitals without the studied intervention as comparators. We will evaluate the effect of the intervention as mean differences of energy consumption between the baseline and with the effect of the intervention, with 95% confidence intervals. Repeated measurements will be synthesised using a standard mean, whereas different measures of the same outcome will be collected and compared according to the most common variable selected.

If ITS studies are included, we will report slope or level change if this information is available, or recalculate them if needed. These will be accompanied by associated standard errors, confidence intervals, and P values (Turner 2021).

If data are not in this format, we will convert them into the required format for the meta-analysis if possible.

Unit of analysis issues

The unit of analysis will be the hospital or clinic.

We will assess whether there are multiple instances of the same outcome being observed. For studies with multiple comparators in multi-arm trials, we will include any arm that meets the inclusion criteria for this review.

In such cases, we will either merge the groups to form a singular pairwise comparison, or adjust the sample size appropriately so that the same individuals do not contribute data more than once, which can be achieved by dividing the shared group into two or more groups. This will improve the accuracy of the comparison (Higgins 2022b).

Dealing with missing data

In the case of missing data from the included studies, we will contact the study authors to supply the required information.

We will also report methods used in the primary analysis and in the sensitivity analysis to assess how sensitive results are to reasonable changes in the assumptions made in the selected studies. For the primary analysis, we will input the missing data with replacement values, and treat these as if they were observed, by imputing the mean, or imputing based on predicted values from a regression analysis (which is preferable). For the sensitivity analysis, we will conduct a multiple imputation method to input missing data.

We will also address the potential impact of missing data on the findings of the review in the Discussion section.

Assessment of heterogeneity

We will assess the characteristics of the included studies to determine whether the hospitals, interventions, and outcomes are sufficiently similar to be pooled in meta-analysis.

If these are not sufficiently similar for a meta-analysis, we will reconsider the comparison groups, analysing the characteristics of studies. If studies are still heterogeneous, we will assess the included studies through a narrative review of the literature. We will use the inconsistency index I^2 to assess statistical heterogeneity among studies in the meta-analysis (Higgins 2022a), as well as the P value from the Chi^2 test. In particular, we will categorise heterogeneity as (Deeks 2022):

- 0% to 40%: might not be important;
- 30% to 60%: may represent moderate heterogeneity;
- 50% to 90%: may represent substantial heterogeneity;
- 75% to 100%: considerable heterogeneity.

The importance of the observed I^2 statistic will depend on the magnitude and direction of effects, and the strength of evidence for heterogeneity. We will downgrade the certainty of the evidence using the GRADE approach when $I^2 \geq 60\%$.

Key methodological characteristics and effect modifiers will be summarised in the Results section, as well as briefly referred to in the Discussion section.

Assessment of reporting biases

We will attempt to reduce reporting bias by including reports from trial registries and sources other than published reports.

If results are missing, we will construct a matrix (with rows as studies and columns as syntheses) indicating the availability of study results for each synthesis to be assessed for risk of bias due to missing results. We will also consider displaying the study in a forest plot, underneath a meta-analysis of studies with available results.

If 10 or more studies are included in the meta-analysis, we will investigate reporting biases (such as publication bias) by building funnel plots using RevMan (RevMan 2024). These will consider the standard error of the effect estimate. We will evaluate funnel plot asymmetry visually and by calculating P values for Begg and Egger's test (Egger 1997). If asymmetry is present, we will perform exploratory analyses to investigate it, including sensitivity analysis.

Data synthesis

Our intention is to carry out meta-analyses according to the type of intervention. We will report mean differences and a pooled estimate on forest plots, with 95% confidence interval, for each of the included studies. No intervention will be considered as a reference. We will adopt the random-effects model of Der Simonian and Laird for the analysis, as studies are estimating different intervention effects. We will perform data synthesis using RevMan (RevMan 2024).

In the case of ITS studies and depending on the data collected, we plan to perform re-analysis in order to overcome limitations in the original analysis and calculate a consistent effect measure for each included study, as explained above (Korevaar 2022). This will be performed by applying autoregressive integrated moving average (ARIMA), restricted maximum likelihood or Prais-Winsten, conducted in the software R (R Core Team 2022). These methods allow an adjustment for autocorrelation and seasonality to avoid unadjusted series that might not reflect a correct weight in the meta-analysis (Turner 2021). Alternatively, we can attempt to carry out logistical, Poisson or linear regression, depending on the data retrieved. If we proceed with a meta-analysis as planned, we will also use multiple effect measures, as this might be common with the interventions listed, or integrate level and slope changes, followed by fitting in the random-effects model (Korevaar 2022). Results will then be exported to RevMan (RevMan 2024).

If a meta-analysis cannot be performed, we will adopt other methods for data synthesis. We will first consider summarising effect estimates, followed by the combination of P values, according to the collected data. In this case, a forest plot can still be presented without calculating the meta-analytic effect. We will consider harvest and albatross plots if a forest plot cannot be created.

If studies are too dissimilar, and we choose not to proceed with synthesis, we will report results using tables (according to study size or GRADE) or present mean differences in a forest plot (Higgins 2022b).

Subgroup analysis and investigation of heterogeneity

We will perform subgroup analyses based on different interventions that impact energy consumption as defined in the list of interventions.

We plan to carry out further subgroup analyses according to outcome (water versus energy: electricity, oil, or gas) and hospital characteristics, including public versus private; built surface area; number of beds; and number of workers (Zaza 2022). As different regions present different policies, we will also carry out a subregional analysis (Cygańska 2021).

There must be a minimum of two studies per subgroup and substantial differences justifying subgrouping and specific analyses.

We will investigate differences between subgroups with a significance test for heterogeneity across subgroup results (Borenstein 2013).

Of note, there are limitations to subgroup analyses, including their observational nature and lower power to detect differences with fewer than 10 studies per category.

We will assess heterogeneity using P values from the Chi^2 and I^2 statistics, calculated with forest plots (Cumpston 2022), if possible.

Sensitivity analysis

In order to include as many pertinent studies as feasible in the review, we plan to conduct the most thorough searches possible. However, when creating a search strategy, it is essential to strike a balance between aiming for comprehensiveness and upholding relevancy.

To examine the robustness of study results, we will conduct a sensitivity analysis for the primary outcomes, energy and water consumption, consisting of analysis of the following:

- studies at low risk of bias in the overall risk of bias assessment;
- studies with a long time frame or with a broad population, to understand their weight in the results;
- cluster-randomised studies;
- studies without complete data.

This will allow an evaluation of whether key methodological factors or decisions have affected the main result.

Summary of findings and assessment of the certainty of the evidence

We will present the overall certainty of the evidence for each outcome according to the GRADE approach, accounting for issues related to internal validity (risk of bias, inconsistency, publication bias, and imprecision) and to external validity such as directness of results (Schünemann 2022).

We will create a summary of findings table based on the methods described in the *Cochrane Handbook* (Higgins 2022a), employing GRADEpro GDT and RevMan (GRADEpro GDT; RevMan 2024). We will use the GRADE checklist and GRADE Working Group certainty of evidence definitions (Meader 2014).

We will downgrade the certainty of the evidence from 'high' by one level for serious (or by two levels for very serious) concerns for each study limitation. We will justify all decisions to downgrade the certainty of the evidence using footnotes and make comments to aid the reader's understanding of the review where necessary. We will define the levels of certainty as follows.

- High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.
- Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
- Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.
- Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

Two review authors (OO and KC) will independently perform GRADE assessment, with any disagreements resolved by discussion or by involving a third review author (JCX). We will justify, document, and incorporate judgements into the reporting of results for each outcome.

We will present a summary of findings table reporting the following outcomes, listed in order of priority:

- energy consumption;
- water consumption;
- energy-related expenditure;
- estimated energy savings;
- estimated savings (in euros) due to interventions;
- estimated greenhouse gases reduction due to intervention.

We will prepare a separate summary of findings table for each comparison.

In the event that meta-analysis is not feasible, we will present the results narratively in the summary of findings table.

ACKNOWLEDGEMENTS

Acknowledgements from the authors

We would like to thank Cochrane Portugal for the logistical assistance during the conceptualisation of this review. We would also like to thank Dr Jonathan Livingstone-Banks, Nuffield Department of Primary Care Health Sciences, University of Oxford, and Charlene Bridges, Information Specialist, Publishing and Technology Directorate, Cochrane Central Executive Team, for providing comments and guidance on searching for evidence.

Editorial and peer-reviewer contributions

The following people conducted the editorial process for this article:

- Sign-off Editor (final editorial decision): Lisa Bero, Cochrane Editorial Board, University of Colorado Anschutz Medical Campus, USA;
- Managing Editor (selected peer reviewers, provided comments and editorial guidance to authors, edited the article): Lara Kahale, Cochrane Central Editorial Service;
- Editorial Assistant (conducted editorial policy checks, collated peer-reviewer comments, and supported the editorial team): Leticia Rodrigues, Cochrane Central Editorial Service;
- Copy Editor (copy editing and production): Lisa Winer, Cochrane Central Production Service;

- Peer reviewers (provided comments and recommended an editorial decision): Valerie Wells, Research Associate - Information Scientist MRC/CSO Social and Public Health Sciences Unit School of Health and Wellbeing University of Glasgow (search), Charlene Bridges, Information Specialist, Publishing and Technology Directorate, Cochrane Central Executive Team (search and methods), Miranda Cumpston, Cochrane Public Health, University of Newcastle, Australia (methods), Dr Gitismita Naik, Assistant Professor, Community Medicine, All India Institute of Medical Sciences, Kalyani, India (clinical), Michael Chaitkin, ThinkWell (clinical), Ed Rubinstein, University Health Network (clinical).

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APPENDICES

Appendix 1. MEDLINE (Ovid) search strategy

1 exp Hospitals/
2 (hospital* or clinic* or "secondary care" or "secondary center*" or "tertiary care" or "tertiary center*").ti,ab.
3 1 or 2
4 Carbon Footprint/
5 (emission* or "net zero" or "greenhouse gas*" or GHG or GHGs or "environmental footprint").ti,ab.
6 (energy adj2 (efficien* or sav* or consum* or expen* or use* or usage or perform*)).ti,ab.
7 (carbon adj2 (footprint or zero)).ti,ab.
8 (water adj2 (efficien* or sav* or consum* or expen* or use* or usage)).ti,ab.
9 4 or 5 or 6 or 7 or 8
10 policy/ or organizational policy/ or environmental policy/
11 (intervention* or program* or project* or strateg* or campaign* or initiative* or policy or policies or action* or respon* or mitigat* or manag* or evaluat* or assess*).ti,ab.
12 10 or 11
13 (heat* or warm* or ventilat* or air or light* or renewable* or green* or "environmentally friendly" or sustainab* or "green building" or educat* or train* or retrofit*).ti,ab.
14 12 or 13
15 (Carbon Footprint/ or (emission* or "net zero" or "greenhouse gas*" or GHG or GHGs or "environmental footprint").ti,ab. or (energy adj2 (efficien* or sav* or consum* or expen* or use* or usage or perform)).ti,ab. or (carbon adj2 (footprint or zero)).ti,ab. or (water adj2 (efficien* or sav* or consum* or expen* or use* or usage)).ti,ab.) adj10 (exp Hospitals/ or (hospital* or clinic* or "secondary care" or "secondary center*" or "tertiary care" or "tertiary center*").ti,ab.)
16 14 and 15
17 exp animals/ not humans.sh.
18 16 not 17

CONTRIBUTIONS OF AUTHORS

José Chen-Xu conceived the study; contributed to the development of the search strategy and intervention definitions; and will be involved in study selection, risk of bias assessment, data extraction, analysis and review.

Irina Kislaya contributed to the study conception, the development of the search strategy, and will be involved in analysis and revision of the study.

Ricardo Fernandes contributed to the study conception, the development of the search strategy, and will be involved in analysis and revision of the study.

Joana Carvalho contributed to the study proposal, the development of the intervention definitions, and will be involved in analysis and revision of the study.

Beatriz Juliet Blanco-Rojas contributed to the study proposal, the development of the search strategy, and will be involved in study selection, data extraction and analysis.

Omnia El-Omrani contributed to the study proposal, the development of the search strategy, and will be involved in data extraction, risk of bias assessment, and analysis.

Edoardo Miotto contributed to the study proposal, the development of the search strategy, and will be involved in study selection, data extraction and analysis.

Katja Čič contributed to the study proposal and will be involved in data extraction, risk of bias assessment, and analysis.

Paulo Boto contributed to the study conception, the development of the search strategy, and will be involved in analysis and revision of the study.

Susana Viegas contributed to the study conception, the development of the search strategy, and will be involved in analysis and revision of the study.

DECLARATIONS OF INTEREST

José Chen-Xu has no conflicts of interest to declare.

Irina Kislaya has no conflicts of interest to declare.

Ricardo Fernandes has no conflicts of interest to declare.

Joana Carvalho has no conflicts of interest to declare.

Beatriz Juliet Blanco-Rojas declared conflict as a public health resident at Hospital Universitari Germans Trias i Pujol, Badalona, Spain.

Omnia El-Omrani declares conflicts of interest due to being the Youth Envoy for the COP27 President.

Edoardo Miotto has no conflicts of interest to declare.

Katja Čič has no conflicts of interest to declare.

Paulo Boto has no conflicts of interest to declare.

Susana Viegas has no conflicts of interest to declare.

SOURCES OF SUPPORT

Internal sources

- No internal support was provided, Other

.

External sources

- No external support was provided, Other

.