Ref: Submission ID e98d6fb2-1591-4c72-9bb7-c56f1cb1baba
Response to reviewers' comments

Dear Professor Kolokotsa,

Thank you for the opportunity to submit a revised draft of the manuscript "Passive and low-energy strategies to improve sleep thermal comfort and energy resiliency during heat waves and cold snaps" for publication in *Scientific Reports*. We appreciate the time and effort you and the reviewers dedicated to providing feedback on our manuscript and are grateful for the insightful comment, which helped us to improve the quality of manuscript. We have incorporated most of the suggestions made by the reviewers. These changes are indicated within the manuscript as tracked changes. Please see below, in blue, for a point-by-point response to the reviewers' comments and concerns. All page numbers refer to the revised manuscript file with tracked changes.

Reviewer Comments:

Reviewer 1

The work presents an excellent comparison of selected measures to improve thermal comfort while sleeping, a highly topical subject considering weather events worldwide and climate change prospects. The work presented is thorough and rigorous, abiding by best practices in the field and subject to common limitations (mainly the need to estimate unobserved performance inside residential settings in an area where subjective perception can be important and difficult to attain). Nevertheless, these limitations are acknowledged, and reasonable estimates are provided in all instances.

The work is recommended for publication following consideration of main comments, which exclusively relate to wording and discussions and not to core findings of estimated effects.

Author response: Thank you!

Main comments:

1. About "We applied our experimentally measured heating and cooling effects to two historical case studies: the 2015 Pakistan heat wave and the 2021 Texas power crisis.". In both cases, heating and cooling effects have been estimated based on extrapolation from laboratory conditions (there referred to as 'experimentally measured'). These sentences, although technically correct, could reflect more closely that the study provides "extrapolated estimates of effects". In the previous, 'estimates' reflect that different individuals would heat or cool differently to what has been shown in laboratory conditions with this manikin, and 'extrapolated' covers application via queried datasets for the case study in Pakistan and modelling for the one in the US.

Author response: We agree with the reviewer's assessment, and we have revised this sentence on Page 1. The revised text reads as follows:

"We extrapolated our experimental findings to estimate heating and cooling effects in two historical case studies: the 2015 Pakistan heat wave and the 2021 Texas power crisis."

2. The presentation of findings might imply that reductions in heat or cold exposure through presented measures represents untapped potential in general. That may be the case for some of the US population (indeed, reference 27 in the discussion refers to New York alone, something the Discussion should acknowledge explicitly). One of the two case studies is in Pakistan, which may lead readers to apply the reasoning of untapped potential to that setting as well. It should be signposted that some of these adaptations are routinely adopted in many countries, if not the vast majority. This is particularly relevant in settings where there is no heating or AC access due to lack of equipment or economic reasons, which may better represent a significant part of the population in the world. Last sentence of the abstract reflects this as it mentions HVAC systems, but it is advisable to stress this in the Discussion (e.g., in the first sentence of the second paragraph, reference 27). From a public health guidelines point of view, the distinction between already realised effect versus untapped potential is important, particularly when interpreting outcomes of past heat waves and cold snaps.

Author response: We agree with the reviewer's assessment and have revised this sentence in the Discussion section on page 9. The revised text reads as follows:

"While passive and low-energy strategies may already be used in many contexts, there remain barriers to their preferential use over conventional HVAC systems when available. A study in New York City, United States, shows that passive strategies are less commonly…"

3. About the three last sentences of the abstract and their counterparts in the discussion. The work does not present (a) data on peak loads or references to that end from an energy systems point of view, nor (b) reviews current advice in public-health guidelines. About (a), it would be advisable to show how peak loads in energy systems do take place during sleep time during these events (which may be different for cold snaps and heat waves). Then it would be useful to see how the novel quantification in this work is translated into estimated power savings. About (b), the use of "starting point" warrants a reflection on how these practices are widely ignored in relevant settings (several of the strategies here studied are already leveraged by dwellers, like a more spread sleeping posture with suitable clothing whenever possible under warm conditions).

Author response: With regards to a) we conducted additional analysis using the model from the 2021 Texas power crisis case study to demonstrate the energy impact of coupling low-energy and passive heating interventions with thermostat setpoint reductions. This is presented in a new Figure 3 on page 8. With regards to b) We do discuss and cite existing public health guidelines on page 2, paragraph starting "Public health agencies have a role…". While it is true that some of the strategies studied are likely already utilized, they do not necessarily appear in public health guidelines nor is there guidance on how these strategies can be used even more effectively.

The following are minor comments for authors consideration that may help readers of this work, at their discretion:

1. Although clear from 'dry heat loss thermal manikin' on 'Approach', it would be helpful to stress at that point that measured cooling effects would be conservative (already addressed in 'Discussion'), given widespread readership of the journal.

Author response: We agree with the reviewer's assessment and have revised this sentence on page 4. The revised text reads as follows:

"While this metric will be conservative, since the thermal manikin cannot measure latent heat loss, such as the evaporative cooling effect from sweating, it still allows us to quantitatively compare the different heating and cooling strategies."

2. A note might expand on the role of light bed clothing may have on drying and diffusing sweat or whether it would always be advisable to remove bedding.

Author response: We agree with the reviewer's assessment and have added a sentence to page 14 in the description of clothing and bedding insulation. The new sentence reads as follows:

"While this study focused on dry heat transfer, it's worth noting that clothing and bedding with the same insulation level could perform differently with regards to latent heat transfer, like the absorption, diffusion, and evaporation of sweat. Common bedding materials like cotton, linen, or polyester, have different hygroscopicity, wicking ability and permeability."

3. The study reports a minor role of surface area contact with mattress. A note might clarify if the same role would be expected in practice (thermal manikin is reported to weight 18kg, adults would be expected to weight 3-4 times more, and firmness of bed support decreases over time).

Author response: We agree with the reviewer's assessment and have added text to page 9. The new sentence reads as follows:

"In reality, a person's surface contact with the mattress will likely be higher than what we modeled in this study due to a real adult weighing approximately 2.9-4x more[66] than the thermal manikin and the firmness of a real mattress will decrease over time. Despite this, we'd still expect a higher contact surface area with clothing or bedding compared to the mattress."

4. At times it seems the work addresses the energy-profligate use of heating and air conditioning alone, not necessarily ventilation (HVAC is the popular acronym, but it seems ventilation still holds as principles would be the same as for the fans used in the study, and to help extract heat whenever possible in hot events). This could also consider noise ratings by fans in these categories and whether such noise ratings would noticeably affect sleep quality (it is anticipated that they would not, but would be helpful to report this explicitly in methods).

Author response: The reviewer is correct in that our study does not address ventilation. The focus of this study is the thermal environment, not air quality. Ventilation is the process of supplying air to and/or removing air from a space for the purpose of controlling air quality. Buildings are usually classified according to their ventilation system as mechanically, naturally, or mixed ventilated. Usually, the air movement from ventilation systems is not at sufficient speed to cool people. The fans we studied are for cooling and are different from the ones used for mechanical ventilation. The fans of a mechanical ventilation system are also typically located within ducts, not the occupied space.

Reviewer 1's point about fans and noise is relevant and was a concern shared by Reviewer 2. We added text to the Discussion, beginning on page 9, on the role of fans on noise. The new paragraph reads as follows:

"While our study focuses on the impact of indoor temperature on sleep quality, fans may contribute to other factors related to the overall indoor environmental quality of the bedroom, such as acoustics. Loud environmental noise from vehicular traffic, aircraft, trains, and wind turbines can be disruptive to sleep[67]. These noises are generally loud and intermittent. On the other hand, soft and constant noise, such as that produced by a white noise machine may aid sleep[68]. The noise from fans, like the ceiling and floor fans in this study, is more like the second of these two and if a DC motor is used, the sound is mostly likely not perceivable, but this is an area for further research."

5. "Passive and low-energy strategies can reduce the sleep time heat or cold exposure by as much as 90%." It would be advisable to report the range observed to depict findings more closely (69-91%).

Author response: We agree with the reviewer's assessment and have revised this sentence on page 1. The revised text reads as follows:

"Passive and low-energy strategies can reduce the sleep time heat or cold exposure by 69-91%."

We did not revise a similar sentence on page 7 because the following sentence describes the lower bound of the results.

Reviewer 2
Thank you for a much-needed paper in an area that is sure to be a major issue in the future, there is a need to further support the use of energy efficient systems that reduce our reliance on energy intensive AC and do so in innovative ways. The paper to me appears to be technically sound and the claims seem reasonable, I have a few clarifications that I think need to be made prior to publication:

Author response: Thank you!

Main comments:

1. Can you explain what is actually meant by low energy? Is there a metric used to define this in the work, it would be great if context was added around the energy related aspect of the work. Evidently some of the measures require limited grid supplied electrical energy, and others do, is there an energy cost that can be described in the work to contextualize the two orders of magnitude difference your mention?

Author response: Low-energy is relative to conventional HVAC systems. We give a typical power rating for conventional heating and cooling systems on page 2. The reviewer's idea to contextualize the energy difference into an energy cost is a good one. We added a comparison of energy cost to our discussion on page 8. The text addition reads as follows:

"The average cost of household electricity in the United States in September 2023 is $0.16[59], which is significantly cheaper than other parts of the world[60]. Therefore, a 3 ton air conditioner would cost $14.40 to run overnight (10 p.m. – 7 a.m.). The average cost of household natural gas in the United States in September 2023 is $21.85/1,000 ft^3 [61]. In the U.S. in September 2022, the average heat content of natural gas delivered to end use sectors is 1,038 Btu/ft^3 [62]. Therefore, a 70,000 Btu/h gas furnace would cost $13.26 to run overnight. Assuming portable heating and cooling options are installed in three bedrooms[63], three window air conditioning units would cost $20.70 to run overnight and three space heaters would cost $6.48 to run overnight. In comparison, our most effective low-energy cooling (ceiling fan) and heating options (heated blanket) use 18 W and 41 W respectively. Either of these devices would cost mere cents to run overnight."

2. Could you clarify the supposed uncertainty in your model for the readers to provide context as to the validity of simulation results?

Author response: We used the prototype residential building models developed by the U.S. Department of Energy. Both the commercial and residential models were developed to be representative of the US building stock. They are used for International Code Council (ICC) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) building energy code development. We did not independently assess their uncertainty but relied on the endorsement by the Department of Energy. More details about the models can be found at https://www.energycodes.gov/prototype-building-models

3. Is the heating and cooling effect figure in Figure 1 in relation to the lab testing or the simulation work? This could be better explained in the text so it is clear that the simulation work is in the second figure (better to be clear I think). Its relatively small, and the format of the paper doesn't help a little (I am assuming is part of the journal format that leads to methods described later in the paper can you correct if this is the case?)

Author response: The heating and cooling effect in Figure 1 is from the laboratory testing. We have added text to the caption to clarify this. As per the journal format, detailed methods appear after results.

4. The baseline is an important part of your work as this forms the basis for explaining the difference between solutions or improvements as a result of solutions. This could be

better explained than it currently is particularly in relation to the simulation results. Can you explain more about the model inputs or testing conditions for the baseline? Is this a low energy building with an improved thermal fabric, is the building statistically representative of residential buildings that are typical to a specific region. Is the building fabric, thermal mass, etc accounted for? Is this purely in cases where natural ventilation is not possible?

Author response: In this paper, we use the term "baseline" to describe the thermal manikin posture, clothing, bedding, and mattress conditions used to calculate the difference in equivalent temperature for the heating or cooling effect calculation. We provide an illustration of this baseline condition in Figure 4.

The reviewer's comments seem to relate to the residential building energy model in the Dallas case study. To avoid ambiguity with the "baseline" condition from the laboratory study, we have changed the label in Figure 2 to "No intervention". This was taken directly from the DOE prototype residential building energy models with the modifications described on page 19. This energy models are representative of the US building stock and take into account all relevant parameters like wall and windows properties, thermal mass, internal loads, heating system, foundation tyle, infiltration rate, etc. We modeled the interior ambient temperature in the Dallas case study this way so we could simulate a heating system shut off and model the lag as the interior temperature cooled down.

5. Did you consider any constraints and how they might effect the adoption of the strategies you refer to? For example you note that the ceiling fan in isolation on a high setting is very effective. Is there any consideration for noise and how this might effect sleep? On this matter, can some explanation be made as to the relationship between sleep quality and temperature. Are there any correlations that can reflect the likely improvement in sleep quality that could be seen?

Author response: We discuss some barriers to adoption of passive and low-energy strategies in our Discussion section on page 9. Per both reviewers' comments, we have added some text about how ceilings fans may impact other dimensions of indoor environmental quality related to sleep, such as acoustics. The revised text, starting on page 7, reads as follows:

"While our study focuses on the impact of indoor temperature on sleep quality, fans may contribute to other factors related to the overall indoor environmental quality of the bedroom, such as acoustics. Loud environmental noise from vehicular traffic, aircraft, trains, and wind turbines can be disruptive to sleep[67]. These noises are generally loud and intermittent. On the other hand, soft and constant noise, such as that produced by a white noise machine may aid sleep[68]. The noise from fans, like the ceiling and floor fans in this study, is more like the second of these two and if a DC motor is used, the sound is mostly likely not perceivable, but this is an area for further research."

6. I agree that more subsidies should be offered for these low-cost systems and I also appreciate the recognition of the fact that the work focuses on sensible or dry or heat

differences. It would be good to contextualise your work with other work on the use of PCM, stack ventilation, natural ventilation or other passive systems. There are limitations for the use of NV in this case, but it the readers would benefit from a bit more discussion in relation to other work.

Author response:
We agree with the reviewer that there are many potential options available to address some of the challenges outlined in the paper. In order to keep the work scoped, we focused on interventions that can be applied on people and their beds and not on the building. Both are important. One could argue that even outside the building (landscape and urban planning) plays a role. We intentionally avoid exploring and comparing building and landscape strategies as cool roof, vegetation, district massing, natural ventilation, thermal mass, shading, etc. Critically comparing these different levels of intervention would be very valuable but outside the scope we gave to ourselves in this work. We added the following to the Discussion on page 9:

"In this paper, our emphasis is on interventions directly applicable to individuals or their sleeping spaces. There are additional interventions associated with enhancing building quality or landscapes, such as weatherization, shading, natural ventilation, and vegetation. While we acknowledge their potential importance and recommend further exploration, they were not specifically addressed in our study."