Evaluating the Impacts of Cool Roofs: A Pilot Study in Thiruvananthapuram District of Kerala

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Abstract

We consider a simple cool roof technology in the form of white reflective paint on the roofs of anganwadis (a government run system of child care in rural India) employing a randomised controlled trial design. We evaluate the impact of the cool roof paint on indoor temperature in the anganwadis, thermal comfort of the staff (teacher and a helper), attendance and cognitive effort of the children attending the anganwadis. The cool roof lowers the roof, ceiling and indoor temperature in treatment anganwadis. Staff from the anganwadis in the treatment group report significantly lower discomfort from the thermal environment. Following these results, in work that is currently ongoing we assess the impact of the cool roof on attendance and cognitive effort of children enrolled in the anganwadis.

Keywords: Education, Environment & Energy, Classroom, Temperature, Thermal comfort, Cognitive effort, Learning outcome, India

JEL Codes: I21, I25, Q54, Q56

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1. Introduction and Background

Evidence confirms an increase in average global temperature of at least 1.1 degree Celsius since 1880 with majority of the warming occurring post 1975 (NASA Ongoing Temperature Analysis). The Intergovernmental Panel on Climate Change (IPCC) special report shows how it is mostly human activities that have driven this change. Rising temperature affects people in various ways. Changes in temperature affect productivity. (Somanathan et al., 2021). Rise in temperature also increases the demand for cooling. India's per capita levels of energy consumption for space cooling is a low 69kWh compared to a world average of 272kWh. Economic growth, rising levels of urbanisation, population growth and other structural changes in the economy are expected to increase this significantly (India Cooling Action Plan 2019).

In this context we consider a low cost technology to reduce temperature inside buildings, in this case, anganwadis (a government run system of child care in rural India). We use a simple cool roof technology in the form of white reflective paint on the roofs of the anganwadis employing a randomised controlled trial design. We evaluate the impact of the cool roof paint on indoor temperature in the anganwadis, thermal comfort of the staff (teacher and a helper), cognitive effort and attendance of the children attending the anganwadis. The study was conducted in Thiruvananthapuram district of the Indian state of Kerala, in collaboration with the Energy Management Centre (EMC) of the government of Kerala. 'Kulirma', a new initiative by the EMC aims to harness the potential of cool roofs, primarily white, reflective roof top paint, to mitigate heat in buildings. The policy aims to transform 500 million square feet of roof area of the state into cool roofs. The pilot phase of this initiative was rolled out in anganwadis of five panchayats in Thiruvananthapuram district.

Anganwadis are a crucial component of early learning among children especially in rural India. A typical anganwadi in Kerala consists of a single room and an adjoining kitchen with a roof area roughly between 500 - 600 sq.ft. Around 10 - 15 children in the age group of 2 - 4 years attend an anganwadi. There is usually a teacher and a helper as staff. The anganwadis function from 9.30 am to 3.30pm. Given the amount of time spent by children in the anganwadis, the importance of a comfortable learning environment cannot be overstated. Temperature plays a crucial role in this.

An increase in temperature has multiple effects in addition to just the discomfort and negative effects on health. Gupta and Somanathan, 2023 shows that a rise in temperature increases the probability of missing work among formal sector workers in the absence of work place climate control. Adhvaryu et al., 2020 study the adoption of energy-efficient LED lighting in garment factories around Bangalore, India. They estimate a negative, nonlinear productivity-temperature gradient and also show that LED lighting, a cooler lighting, raises productivity on hot days.

In their study Park et al., 2020 identify a negative effect of heat on learning and they also show that air-conditioning might mitigate this effect. T. Garg et al., 2020 show that high temperatures reduce math and reading test scores among school-age children and identifies agricultural income as one mechanism driving this relationship. But temperature can also affect learning outcomes and cognitive effort physiologically too. Ambient temperature raises brain temperature and the brain's chemistry, electrical properties and functions are all highly temperature sensitive. (Bowler and Tirri, 1974, Yablonskiy et al., 2000).

Several studies across the globe have confirmed the temperature reduction properties of various cool roofs technologies.The cool roof technology of painting the roofs white relies on the high Solar Reflective Index (SRI) of the paint whereby sunlight will be reflected off from the roof keeping the roof, ceiling and hence indoors cooler.

Androutsopoulos et al., 2017 in an experiment in Greece, uses paint coating on the roof of a school building and compares it to a similar nearby building. They confirm a temperature reduction in the range of 1.3 - 1.9 degree Celsius. In the Indian context, V. Garg et al., 2016 monitor two schools, one in Hyderabad and the other in Nagpur for 10 weeks and looks at the impact of a high - albedo paint coating. They show significant reduction in indoor, under-deck and over-deck temperatures. In a study conducted in the urban slums of Ahmedabad, Gujarat Vellingiri et al., 2020 shows that thermocol insulation, solar reflective white paint on the outer roof and modular roof are effective in reducing indoor temperature. Bhatia et al., 2011 uses a calibrated model across five climatic zones to check the effectiveness of cool roofs and shows that cool roofs are most effective in warm and humid climatic regions and gives the maximum energy savings.

The comprehensive review, Black-Ingersoll et al., 2022, while confirming the impact of cool roofs on indoor and roof temperature and thermal comfort, also shows the lack of a robust impact evaluation. Our primary contribution through this study is to provide a robust impact evaluation of the cool roofs by using a randomised controlled trial framework. We will also be contributing to the very limited literature in the Indian context on the impact of classroom features on cognitive effort and attendance.

In our study we find a significant effect of the cool roof paint in reducing indoor temperature. Roof, ceiling and indoor temperature in the treatment group anganwadis are significantly lower than those in the control group. We also find significant impact on thermal comfort of the anganwadi staff. Staff in the treatment anganwadis report lesser discomfort. The analysis on the data from a set of puzzles to evaluate cognitive effort of children enrolled in the anganwadis is ongoing along with the analysis on the impact of the cool roofs on attendance of the children.

2. Intervention

We consider a simple cool roof technology in the form of white reflective paint on rooftops. Anganwadis with a plain concrete, exposed roof were included in the study. A typical anganwadi has a roof area of around 500 sq.ft. Roofs of the anganwadis in the treatment group were painted using white reflective paint with a high solar reflective index (SRI). The paint is expected to reflect off sunlight making the roof, ceiling and indoor cooler.

The study was conducted in five panchayats of Thiruvananthapuram district of the Indian state of Kerala. The panchayats are Andoorkonam, Kattakada, Manikal, Perumkadavila and Pullumpara. Anganwadis which were found suitable in terms of the condition of the roof were divided into treatment and control group. 36 anganwadis were in the treatment group and 32 in the control. The intervention could not be undertaken in 3 of the anganwadis. In two instances water was not available for doing the painting and in one instance aluminium roofing was done in the anganwadi post treatment assignment and before the roll out of the intervention.

The thermal comfort survey was undertaken with the anganwadi staff comprising of a teacher and a helper both at the baseline and at the endline. In all instances in our study these were women. An activity involving an age-appropriate puzzle was conducted with the children attending the anganwadis. This was also undertaken both at the baseline and endline.

2.1 Timeline

Thermometers were installed in the anganwadis in the last week of February 2024 and the maximum temperature were recorded on a daily basis. The baseline surveys were completed in the first two weeks of March 2024.The roll out of the intervention started on 20th March 2024 and was completed on 16th April 2024. The endline surveys were completed in the third week of May 2024 along with thermal imaging in all the anganwadis.

3. Data

Data on temperature was collected on a daily basis using thermometers installed in the anganwadis. Primary surveys were conducted at the baseline and endline to collect data on the other relevant variables. In this section we discuss the key variables of interest in this study.

3.1 Temperature

Maximum and minimum temperature was recorded on a daily basis using a thermometer installed in the anganwadi. Also, the temperature during both the thermal comfort surveys and the puzzle activity were recorded. Additionally thermal imaging of the roofs and the ceilings were also undertaken at the endline.

3.2 Thermal comfort

The anganwadi staff were asked about the thermal comfort of their environment in the survey.

The following three questions were asked to the anganwadi staff. They gave their responses on a Likert scale.

- How do you feel about the temperature of this classroom at the moment? : Respondents gave their reply on a scale of 1 - 7 with 1 being cold and 7 representing hot. A higher score represents a hotter perception.
- How comfortable are you with the thermal environment in your classroom at the moment? : In this case again the respondents gave their reply on a scale of 1 - 7 with 1 being 'too comfortable'. A higher score indicates higher level of discomfort.
- What is your desired temperature state in the classroom? : The respondents gave their reply on a scale of 1 - 3 with 1 representing 'cooler' 2 for 'no change' and 3 being ' warmer'.

3.3 Cognitive effort

An age-appropriate set of puzzles were used in an activity with the children again both before and after the intervention. The children had to sort and arrange a set of blocks according to the shape. A total of 9 such blocks were there. We measured both the number of blocks arranged in 2 minutes and also the time taken to complete the full set. The activity was stopped at 4 minutes and it was also noted whether the child was able to complete the puzzle or not.

3.4 Attendance

Attendance data of children was collected from the anganwadis for the months of January, February , March, April and May for both the year of 2023 and 2024.

3.5 Baseline features of the sample and balance

Table 1 gives some of the features of the participants in the thermal comfort survey. A total of 135 anganwadi staff participated in this survey across the anganwadis. All anganwadi staff were women. Table 1 also gives the key outcome variables across the two groups at the baseline. There is no statistical difference in the temperature values measured during the time of the survey. The surveys were held between 11 am to 1pm. And given the results for the temperature difference during the time of the survey, as expected, there is no difference in the responses to the questions regarding thermal comfort.

Some of the features of the sample for the anganwadi activity at the baseline is given in Table 2 along with the key outcome variables. 559 children took part in the anganwadi activity. While there are no differences between the treatment and control group in the thermal comfort survey, we have a larger proportion of girl children in the treatment group for the anganwadi activity and we also see that the children in the treatment group took approximately 9 seconds more to complete the task than those in the control group. We control for these differences in the final analysis.

	Full sample	Control	Treatment
Thermal comfort			
Age	48.98	48.34	49.56
Proportion of female	100	100	100
Temp during the survey	31.31	31.45	31.20
Temp perception	5.53	5.41	5.65
Comfort	5.10	4.92	5.25
Desired temperature	1.12	1.14	1.10
N	135	64	71

Table 1: Baseline Features of the Sample

Asterisks *,**,*** represent significant difference with respect to the control group at 10%, 5% and 1% significance respectively.

	Full Sample	Control	Treatment
Anganwadi puzzle activity			
Age	3.19	3.16	3.20
Proportion of female	48.3	44.27	51.85*
Temp during the activity	31.07	31.09	31.04
Score	7.70	7.80	7.62
Time taken	110.06	105.26	114.28*
N	559	262	297

Table 2: Baseline Features of the Sample

Asterisks *,**,*** represent significant difference with respect to the control group at 10%, 5% and 1% significance respectively.

4. Methodology

4.1 Temperature

Data on daily maximum temperature from the thermometers installed in the anganwadis can be used for evaluating the effect of the cool roof paint on indoor temperature. A comparison of the mean of daily maximum temperature across the treatment and control groups in the pre and post intervention period can be used for identifying the impact of the intervention on indoor temperature. A double difference would be ideal in this case given the possibility of baseline differences in temperature. Additionally data from thermal imaging at the anganwadis shall help identify the mechanism clearly by comparing the roof, ceiling and indoor temperature.

4.2 Thermal comfort variables

A comparison of the thermal comfort variables across the treatment and control groups at the endline can be undertaken using the following framework.

$$y_{ijp} = \gamma_o + \gamma_1.T_{ijp} + \gamma_2.X + \theta_p + \epsilon_i \tag{1}$$

where y_{ijp} is the thermal comfort variable at endline for individual i in anganwadi j in panchayat p. T_{ijp} ($Treatment$) is a dummy variable denoting treatment status and takes a value of 1 if respondent i from panchayat p is from an anganwadi j in the treatment group and 0 otherwise. X is a vector of controls that includes the baseline value of the corresponding thermal comfort variable and θ_p denotes panchayat level fixed effects. γ_1 is the coefficient of interest and a negative γ_1 will show the treatment improving thermal comfort.

The responses to the thermal comfort questions were on a Likert scale. Hence the above specification will be estimated using an ordered probit framework.

The above framework can provide us with a comparison of the treatment and control groups. What the intervention actually aims to do is to reduce the temperature in the anganwadis. And in the real sense this change(reduction) in temperature is the treatment. The following specification can help us identify the impact of temperature on thermal comfort.

$$y_{ijp} = \alpha_o + \alpha_1.temp_{ijp} + \alpha_2.X + \epsilon_i \tag{2}$$

where $temp_{ijp}$ ($Temperature$) is the temperature recorded during the thermal comfort survey for respondent i in anganwadi j in panchayat p.

But in our case temperature cannot be treated as exogenous. The treatment though introduces an exogeneous variation in the temperature across anganwadis. The treatment was randomly assigned and we have had near perfect compliance (other than the 3 instances where painting could not be completed owing to logistical issues). The treatment hence satisfies the exclusion criteria for an instrument. It also satisfies the relevance condition given the expected impact on temperature. And hence we will be able to analyse the impact of temperature on thermal comfort using an ordered probit framework and instrumenting for temperature using the treatment status.

The first stage regression in this case would be,

$$temp_{ijp} = \beta_o + \beta_1.T_{ijp} + \delta_p + \epsilon_{ijp} \tag{3}$$

where T_{ijp} is a dummy variable denoting treatment status and takes a value of 1 if respondent i is from an anganwadi j in the treatment group and 0 otherwise. δ_p denotes panchayat fixed effects.

Using the fitted values of $temp_{ijp}$ from the first stage in equation (2), α_1 becomes the coefficient of interest. A positive α_1 would tell us that an increase in temperature worsens thermal comfort.

Given the nature of the specification in all cases above, values of the coefficients cannot be interpreted in a useful manner. We consider the average marginal effects which prove to be more useful.

In all specifications given above standard errors will be clustered at the anganwadi level.

5. Results

5.1 Effects on temperature

Daily maximum temperatures were recorded using the thermometers installed in the anganwadis. Table 3 gives the mean of daily maximum temperatures for the control and treatment groups both during the pre-intervention and post-intervention periods. The days on which the rooftop paintings was done have been excluded. Accounting for the difference in means across the two groups prior to the intervention, we see a double difference estimate of -1.30 degree Celsius. The treatment anganwadis are significantly cooler than the control group anganwadis.

	Control	Treatment	Diff in means
Pre-intervention	33.34	33.50	0.16
Post - intervention	33.46	32.32	-1.14***
Difference in Difference = -1.30***			

Table 3: Mean of daily maximum temperature (in degree Celsius)
Asterisks *,**,*** represent significant difference with respect to the control group at 10%, 5% and 1% significance respectively.

To identify clearly the mechanism of how the roof paint works we conducted thermal imaging of the roofs and the ceilings in all the study anganwadis in 4 out of 5 panchayats during the endline surveys. [1]

Figure 1 summarizes the results from this exercise and confirms the mechanism whereby the paint that was used reduces indoor temperature. Both the roofs and the ceiling of anganwadis are significantly cooler in the treatment group. The mean of the maximum roof temperature is approximately 11 degrees lower in the treatment anganwadis as compared to the control group. The ceilings of the anganwadis in the treatment group are approximately 5 degrees cooler than those in the control group. Its clear from these results that the white paint that was used reflects off sunlight from the roofs thereby reducing heat transfer to the ceilings and indoors.

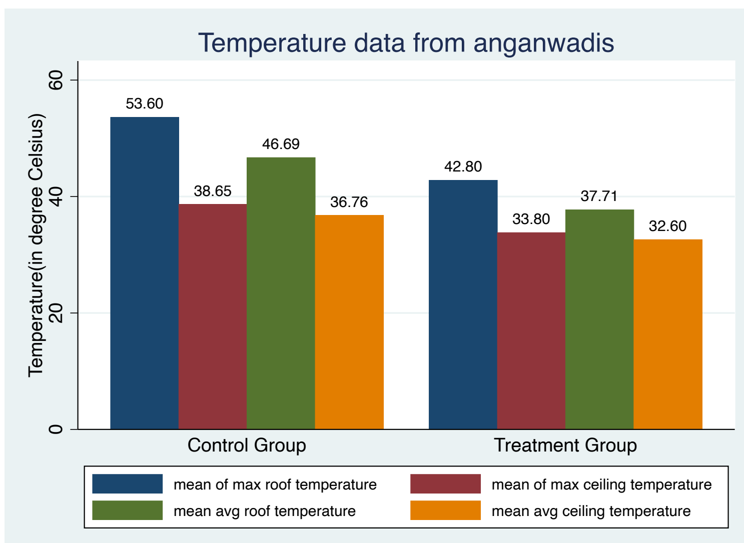

Figure 1: Results from the thermal imaging done at the endline

5.2 Effects on Thermal Comfort

Thermal comfort surveys with anganwadi staff were held both at the baseline and endline. These surveys were held during a rough window between 11 am - 1 pm in

[1] This exercise couldn't be completed due to heavy rains in Perumkadavila. An attempt to do this again was also not successful because of rains and also mould growth and unclean surfaces on the roofs in many cases

both the groups to ensure comparability. 113 out of the 135 respondents who took part in the survey at the baseline also took part in the endline survey. Cases of attrition here were driven by retirement/transfer of teachers.

In Table 4, we look at a comparison between the treatment and control groups using an ordered probit regression. For the third question on thermal comfort - the desired temperature - respondents in both control and treatment group reported wanting a cooler temperature and hence there was no difference in this case. The dependent variables that we consider in Table 4 - comfort with the thermal environment and perception regarding the temperature are on a Likert scale and hence we consider an ordered probit regression. Column (1) in Table 4 has comfort with the thermal environment at endline as the dependent variable and column (2) has temperature perception at endline as the dependent variable. For the variable 'thermal comfort with the environment', a higher value denotes greater level of discomfort and for temperature perception again a higher value represents a warmer(hotter) perception. In both thermal comfort regressions in Table 5 we control for the baseline value of the dependent variable and also include panchayat level fixed effects. We see that the treatment has a negative and significant impact on both thermal comfort with the environment and also the temperature perception. Respondents in the treatment group report a cooler(less hotter) perception regarding temperature and are also reporting a higher level of comfort with the thermal environment . Given the nature of the dependent variable here, the magnitude of the coefficient doesn't have any useful interpretation in itself.

To evaluate the impact of temperature on thermal comfort we consider the use of an instrumental variable framework within the ordered probit methodology. Treatment status is used as an instrument for temperature. Table 5 gives the results from an

Table 4: Comparison between treatment and control groups for thermal comfort

	Dependent variable: Comfort with thermal environment	Dependent variable: Temperature perception
	(1)	(2)
Treatment	-0.73***	-0.73***
	(0.237)	(0.276)
	[0.002]	[0.008]
Baseline	Yes	Yes
Panchayat FE	Yes	Yes
Method	Ordered probit	Ordered probit
Observations	107	107

Notes: i. Asterisks denote the significance levels: *** p<0.01, ** p<0.05, * p<0.1; ii. Standard errors are clustered at the *anganwadi* level; iii. Standard errors are reported in the parentheses while p-values are reported in square brackets; iv. "Baseline" variable captures the baseline value of the respective dependent variable.

ordered probit with IV regression. Table 5 also gives the first stage regression results. The F-statistic is approximately 28 and exceeds the thumb-rule value of 10. Column (1) in Table 5 has comfort with the thermal environment at endline as the dependent variable and column (2) has temperature perception at endline as the dependent variable. Controls for baseline value of the dependent variable and panchayat level fixed effects are included in both cases. Temperature has a positive and significant effect in both cases, meaning an increase in temperature reduces thermal comfort and also results in the respondents reporting a warmer perception of the temperature. The coefficient as such doesn't have any useful interpretation. But what will be useful is to consider the marginal effects of temperature on the predicted probabilities of each level of the outcome variable.

Figure 2 gives the marginal effects of temperature on the temperature perception. The figure gives the change in the proportion of the sample reporting each level of the outcome variable, here temperature perception, for a one unit increase in temperature along with the 95% confidence interval. No respondent reported a temperature perception level of 1 (cold) in our data. It is clear that an increase in temperature of

Table 5: Impact of temperature on thermal comfort

	Dependent variable: Comfort with thermal environment	Dependent variable: Temperature perception
	(1)	(2)
Temperature	0.78***	0.82***
	(0.110)	(0.945)
	[0.000]	[0.000]
Baseline	Yes	Yes
Panchayat FE	Yes	Yes
Method	Ordered probit with IV	Ordered probit with IV
Observations	107	107
First-stage regression (Dependent variable: Temperature)		
Treatment	-0.59*	-0.59*
	(0.349)	(0.351)
	[0.090]	[0.092]

Notes: i. Asterisks denote the significance levels: *** p<0.01, ** p<0.05, * p<0.1; ii. Standard errors are clustered at the *anganwadi* level; iii. Standard errors are reported in the parentheses while p-values are reported in square brackets; iv. "Baseline" variable captures the baseline value of the respective dependent variable.

one degree reduces the proportion of the sample reporting a temperature perception on the cooler side and increases the proportion of the sample reporting a warmer perception. There is a reduction of approximately 12.5% in the proportion of the sample reporting lower levels of temperature perception (levels 2, 3 & 4- perception on the cooler side) and this is redistributed across the higher levels(levels 5, 6 & 7 - hotter/warmer perception).

Figure 3 gives the average marginal effects of temperature on the comfort with the thermal environment variable. This shows how the proportion in the sample reporting each level of the outcome variable, here thermal comfort, changes with a one unit increase in temperature. In our data, no respondent reported a thermal comfort level of 1 (too comfortable). As we can see from the figure an increase in temperature by one degree reduces the proportion of the sample reporting lower levels of discomfort with the thermal environment and increases the proportion of those reporting higher levels of discomfort. The approximately 6.5% reduction in the proportion reporting lower levels of discomfort (levels 2,3 & 4) is distributed across the higher levels of discomfort(levels 5, 6, & 7).

These results confirm the impact of the intervention in improving thermal comfort. Respondents in treatment group anganwadis report better thermal comfort .Results on the impact of the treatment on temperature confirms the mechanism driving this. Improved comfort can mitigate negative productivity effects which would otherwise have resulted from an increase in temperature as shown in the literature.

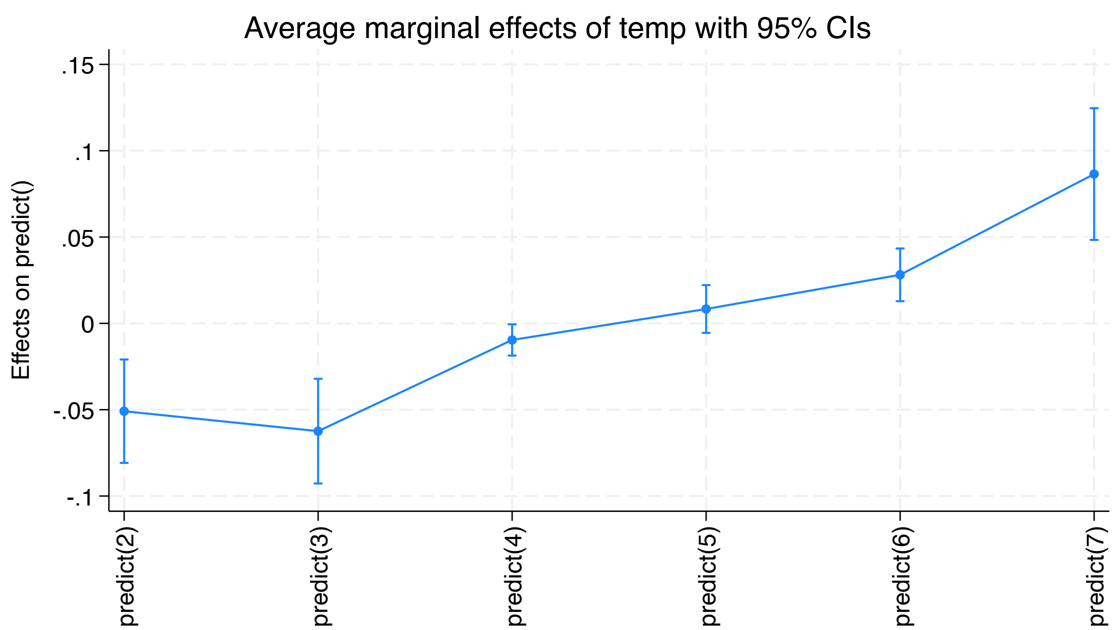

Figure 2: Marginal effects of temperature on temperature perception

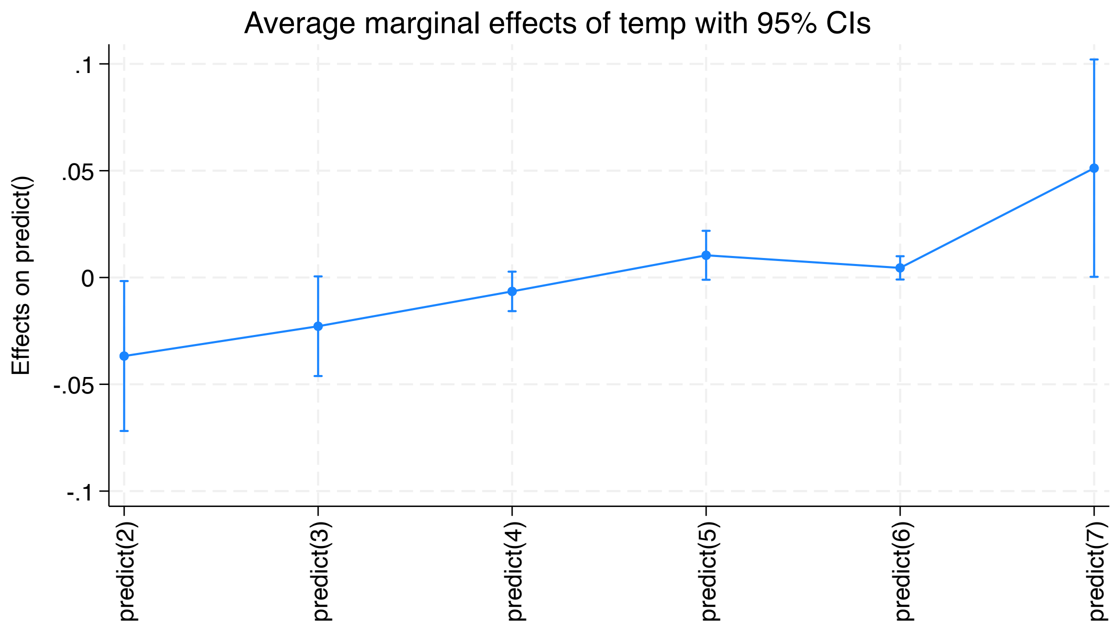

Figure 3: Marginal effects of temperature on comfort with thermal environment

6. Discussion

Having identified the impact of the cool roof intervention on temperature and on thermal comfort, next we would be evaluating the impact of the intervention and reduced temperature on cognitive effort and attendance of children enrolled in the anganwadis. Temperature has been shown to improve the functioning of the brain via a physiological effect. (Bowler and Tirri, 1974 and Yablonskiy et al., 2000). This forms the motivation for considering the impact of the intervention on cognitive effort. The rest of the analysis is expected to be completed soon.

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